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Some tests on the measurement of the modulation transfer function technique of screen-film system

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Abstract

A method to determine the modulation transfer function (MTF) of screen-film system was tested by measuring the MTF of a mammography and a conventional radiography systems. The method was further tested by measuring MTF obtained from x-rays exiting from two tissues equivalent phantoms. The MTF of the mammography system was higher than that of conventional radiography system confirming general correctness of the method. The MTFs obtained from the two equivalent phantoms agreed very well which indicate that the equivalent could be shown by the method. The study gives the experimental proof for the appropriateness of the method.

Key words:

Modulation transfer function

Diagnostic imaging

Radiography

Mammography

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Introduction

The spatial resolution properties of a diagnostic x-ray screen-film system, described by the modulation transfer function (MTF), is one of the important imaging parameters to be determined for a quantitative physical evaluation of imaging performance of the screen-film system. There are at least three methods in determining the MTF of the screen-film system namely the slit, the square wave response, and the edge response methods [1-3]. A practical method using the square wave response has been proposed by Cantell [4] for MTF measurement in a hospital environment. Work to test the method has yet to be performed. In this work, an investigation on the range of MTF expected from the measurement method was performed by measuring the MTF of a mammography system and comparing it with a conventional radiography system. The measurement method was further tested by measuring the MTF obtainable from two tissue equivalent phantoms.

Materials and method

MTF measurement via the square wave response method has been described elsewhere [4]. Briefly, a bar pattern test object is placed on the screen-film combination and an image of the pattern is made by exposing the screen-film to x radiation and developing the radiograph. Type 53 PTW-Freiburg bar pattern (available from Facility for the Assessment of X-ray Imaging at Leeds University, The General Infirmary, Leeds) with 19 groups of line pairs of 0.05 mm lead thickness was used for the measurement. Each line pair group has four line pairs, except the first which has two. The groups are 0.25, 0.5, 0.6, 0.7, 0.85, 1.0, 1.2, 1.4, 1.7, 2.0, 2.4, 2.9, 3.5, 4.2, 5.0, 6.0, 7.0, 8.5, and 10 line pairs per mm. The radiograph is digitised by a microdensitometer (Photoscan System P-1000, Optronics International Inc., Chelmsford, Massachusetts, USA). Optical density values obtained from the process were converted to relative exposure values by the Hurter & Driffield (H & D) curve of the radiograph. The square wave response, $r(u)$, was determined from the ratio of measured image contrast to the object contrast. The sine wave response or the MTF, $R(u)$, was calculated from the square wave response using [5]:

$$R(u) = \frac{\pi}{4} \left[r(u) + \frac{r(3u)}{3} - \frac{r(5u)}{5} + \frac{r(7u)}{7} + \frac{r(11u)}{11} - \frac{r(13u)}{13} - \frac{r(15u)}{15} - \frac{r(17u)}{17} - \frac{r(19u)}{19} - B_k \frac{r(ku)}{k} \dots \right] \quad (1)$$

where k takes on the odd values 1, 3, 5, etc., and B_k is 1, 0, or -1 according to the formulae

$$\begin{aligned} B_k &= (-1)^m (-1)^{(k-1)/2} & \text{if } p &= m, \\ B_k &= 0 & \text{if } p < m. \end{aligned} \quad (2)$$

and m is the total number of primes into which k can be factored, and p is the number of different prime factors in k . All calculation was done via a purposely written computer program written in C++ developed by Cantell [4], and further developed by the author.

The microdensitometer scanning aperture used in the measurement was of a square shape 0.0125 mm by 0.0125 mm, the sampling interval was $\Delta x = 0.0125$ mm, thus the Nyquist critical frequency was $1/2\Delta x = 40 \text{ mm}^{-1}$. The square wave bar pattern has the highest line pairs of 10 mm^{-1} , corresponding to a line pair occupying a distance of 0.1 mm. The spatial frequency of interest in medical radiography is in the range of 0-10 cycles/mm, thus the aliasing effect was negligible for this system.

Measurements on a mammography system (Siemens Mammomat 2 with Kodak Min-R screen, at the Aberdeen Royal Infirmary) were made to get estimates of the difference of its MTF compared with a conventional radiography system. The question was a modest one: The resolution property of a mammography system is known to be higher than that of a conventional radiography system, would the method of MTF measurement show this? In this experiment the tube potential was 28 kVp, the focus-to-film distance was 23 inches. A 2.5 cm thick perspex slab was placed on the screen-film cassette, and the bar pattern was placed on the slab.

For the conventional radiography system, the tube potential was fixed at 81 kVp, and a 16 mm thick aluminium phantom was affixed to the x-ray window. The focus-to-film distance 1.5 m. The screen-film system used was Kodak Lanex Regular/T Mat G. Measurements were made in the Outpatient X-ray Room, Aberdeen Royal Infirmary.

At 80 kV, x-rays which pass through 16 mm Al produces a beam with equivalent spectra and beam quality to that which pass through 20 cm of water [6]. To use this fact in testing our method, a water phantom was constructed following sub-clause 4.1.3.1 of British Standard 5913 [7]. This was a cylindrical water-filled closed-box phantom having a diameter of 50 mm and a height of 20 cm including walls. The walls of the phantom was made of polymethylmethacrylate with a thickness of 10

mm. Metal bracing support for the phantom to facilitate mounting to the x-ray tube was also constructed.

For these experiments, the water phantom was affixed to the diaphragm box of the x-ray tube, and the tube potential was fixed at 81 kVp. The screen-film system used was also Kodak Lanex Regular/T Mat G.

Results and discussion

Figure 1 shows the three sets of results on a single graph, together with the fitted curves of the results. The fits were made according to a model proposed by Boone and Seibert [8]. For the mammography system, the modulation values up to 7 line pairs per mm could be determined by the method. For the conventional radiography system these values were between 4–5 line pairs per mm. The MTF for the mammography system was higher than that of the conventional radiography system. Table 1 shows that the modulation transfer factors of the mammography system were higher than those of the radiography system (with the 16 mm Al filter) by 0.41, 0.60, 0.56, 0.45, 0.33 units at spatial frequencies 1.0, 2.0, 3.0, 4.0, 5.0 cycles/mm respectively. The modulation transfer factors of the mammography system were 1.76, 3.75, 6.21, 8.13, 9.09 times the modulation transfer factors of the radiography system at the mentioned spatial frequencies respectively. Thus this test did show the expected result that mammography has higher resolution properties than conventional radiography.

Table 2 gives the numerical result for the aluminium phantom. The result was the average from 7 images. The average standard deviation of the MTF values was 0.021, whilst the maximum standard deviation of the MTF values was 0.032 at 1.00 cycle/mm. The average percentage variation (coefficient of variation) was 6.99%, whilst the maximum percentage variation was 15.20% at 3.50 cycles/mm.

Table 3 gives the numerical result for the water phantom. The result was the average of 6 images. The average standard deviation of the MTF values was 0.019, whilst the maximum standard deviation of the MTF values was 0.037 at 1.20 cycles/mm. The average percentage variation (coefficient of variation) was 5.57%, whilst the maximum percentage variation was 12.07% at 2.00 cycles/mm.

It was proposed that to simulate a clinically realistic exit spectrum from human tissue a 20 cm water phantom [9] might be employed. It was also proposed that at 80 kV, x-rays which pass through 16 mm Al produce a beam with equivalent

spectra and beam quality to those which pass through 20 cm of water [6]. We measured the MTF for both phantoms to see if our method of measurement could indicate the equivalence. It can be seen that the MTFs from the water and the aluminium phantoms were almost the same – this supports the claim that both exit beam spectra are equivalent, and demonstrates that the method of measurement could indicate the equivalence.

MTF measurements for the water and aluminium phantoms gave average standard deviation for the modulation transfer factor of 0.019 and 0.021 respectively. In their screen-film MTF measurement using the slit method Doi *et al.* [2] found that the average standard deviation for the modulation transfer factor at spatial frequencies less than 10 cycles/mm was 0.011. If the average standard deviation of the modulation transfer factor is regarded as an indicator of reproducibility, our results were of a poorer reproducibility than those of theirs. It must be noted that their results represented the state of the art of the laboratory based measurement in those years, while ours were obtained from measurements made in x-ray rooms in a hospital. However, reproducibility is not a measure of accuracy of the measurement. Thus, issues related to the accuracy of the measurements need further investigation.

Conclusion

This study has indicated that the method of MTF measurement via the square wave response is appropriate for measurements in a hospital setting. The results show that the MTF of the mammography system was higher than the MTF of the radiography systems. The MTFs from the water and the aluminium phantoms were almost the same – this supports the claim that both exit beam spectra are equivalent, and demonstrates that the method could indicate the equivalence. In the MTF measurements the water and aluminium phantoms gave average standard deviation for the modulation transfer factor of 0.019 and 0.021 respectively, which are slightly lower than values obtained from laboratory based measurements.

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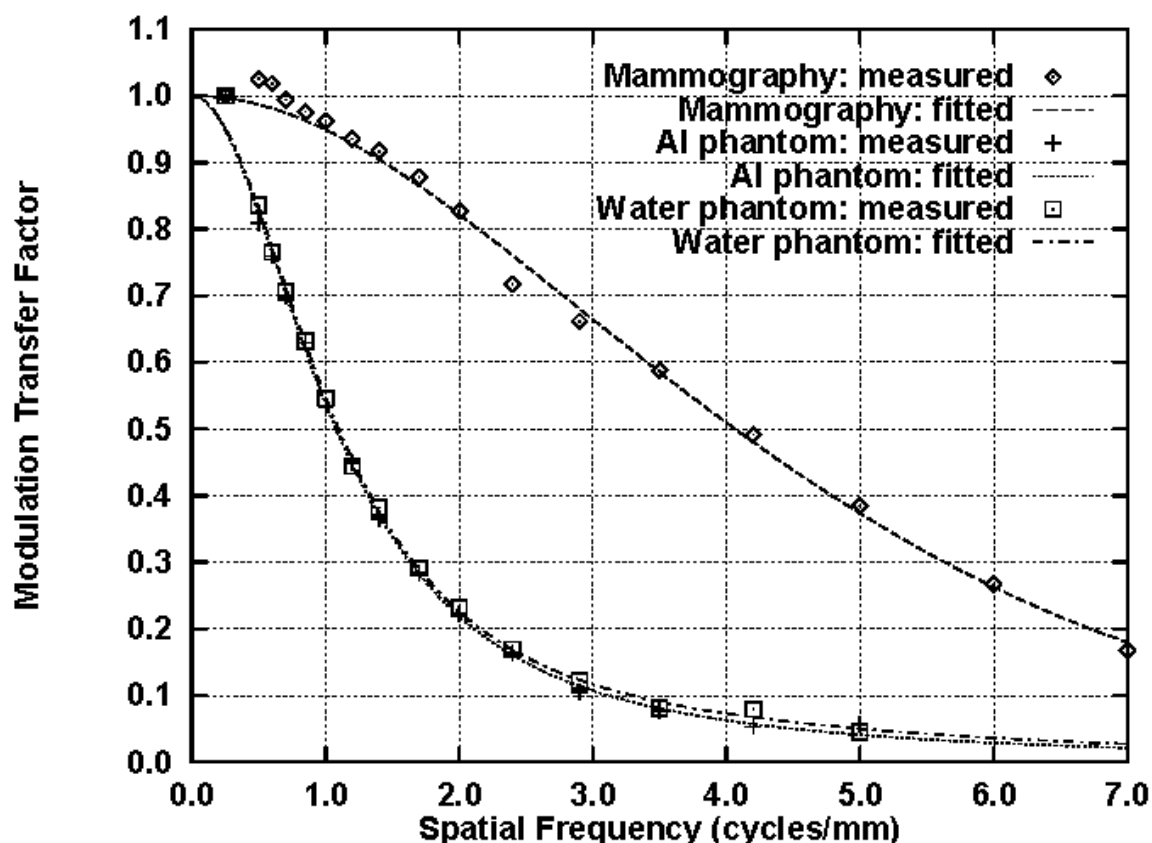


Figure 1. Comparison of the three results in a single graph. The various data points are indicated in the graph while their curve fits are also shown. The MTF of the mammography system (◇) is higher than that of the conventional radiography (+). The MTFs obtained from two tissue equivalent phantoms, the 16 mm Al phantom (+) and the 20 cm water phantom (□) are identical.

Table 1. Comparison of the MTF values at selected spatial frequencies for the mammography and the conventional radiography systems.

| Spatial Frequency (cycles/mm) | Mammography MTF (a) | Radiography MTF (b) | Difference a-b | % difference (a-b)/b*100 | Ratio a/b |
|-------------------------------|---------------------|---------------------|----------------|--------------------------|-----------|
| 1.0 | 0.95 | 0.54 | 0.41 | 76 | 1.76 |
| 2.0 | 0.82 | 0.22 | 0.60 | 275 | 3.75 |
| 3.0 | 0.66 | 0.11 | 0.56 | 521 | 6.21 |
| 4.0 | 0.51 | 0.06 | 0.45 | 713 | 8.13 |
| 5.0 | 0.37 | 0.04 | 0.33 | 809 | 9.09 |

Table 2. Numerical result of the MTF obtained for a 16 mm thick aluminium phantom.

| Spatial Frequency (cycles/mm) | Average MTF (a) | Stdev (b) | % Variation (b/a*100) |
|-------------------------------|-----------------|-----------|-----------------------|
| 0.25 | 1.000 | 0.000 | 0.00 |
| 0.50 | 0.809 | 0.019 | 2.39 |
| 0.60 | 0.760 | 0.032 | 4.19 |
| 0.70 | 0.699 | 0.023 | 3.30 |
| 0.85 | 0.629 | 0.029 | 4.56 |
| 1.00 | 0.532 | 0.032 | 6.00 |
| 1.20 | 0.450 | 0.022 | 4.99 |
| 1.40 | 0.365 | 0.021 | 5.82 |
| 1.70 | 0.284 | 0.024 | 8.40 |
| 2.00 | 0.222 | 0.026 | 11.87 |
| 2.40 | 0.164 | 0.020 | 12.47 |
| 2.90 | 0.105 | 0.012 | 11.66 |
| 3.50 | 0.077 | 0.012 | 15.20 |
| 4.20 | 0.053 | N/A | N/A |
| 5.00 | 0.058 | N/A | N/A |
| | Min | 0.000 | 0.00 |
| | Max | 0.032 | 15.20 |
| | Average | 0.021 | 6.99 |

Table 3. Numerical result of the MTF obtained for a 20 cm water phantom.

| Spatial Frequency (cycles/mm) | Average MTF (a) | Stdev (b) | % Variation (b/a*100) |
|-------------------------------|-----------------|-----------|-----------------------|
| 0.25 | 1.000 | 0.000 | 0.00 |
| 0.50 | 0.836 | 0.019 | 2.25 |
| 0.60 | 0.766 | 0.014 | 1.87 |
| 0.70 | 0.706 | 0.023 | 3.19 |
| 0.85 | 0.631 | 0.028 | 4.42 |
| 1.00 | 0.546 | 0.032 | 5.90 |
| 1.20 | 0.444 | 0.037 | 8.30 |
| 1.40 | 0.382 | 0.027 | 7.09 |
| 1.70 | 0.291 | 0.021 | 7.38 |
| 2.00 | 0.232 | 0.028 | 12.07 |
| 2.40 | 0.169 | 0.012 | 6.99 |
| 2.90 | 0.121 | 0.011 | 8.80 |
| 3.50 | 0.081 | 0.004 | 5.34 |
| 4.20 | 0.079 | 0.003 | 4.41 |
| 5.00 | 0.046 | N/A | N/A |
| | Min | 0.000 | 0.00 |
| | Max | 0.037 | 12.07 |
| | Average | 0.019 | 5.57 |