The detective Modulation Transfer Function applied to scanned digital radiographic detectors.

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Abstract

An extension of the traditional modulation transfer function (MTF), the detective MTF, is proposed for the evaluation of the resolution of X-ray imaging detectors with non-uniform efficiency on the scale of individual detector elements. The dMTF is shown to give a better representation than does the MTF of the improved resolution reported when the readout of the detectors is enhanced.
1 Introduction

The resolution of an imaging detector is frequently expressed in terms of a modulation transfer function (MTF); the Fourier transform of the line spread function (LSF) in one dimension, or of the point spread function (PSF) in two dimensions \cite{1}. But for certain kinds of detector \cite{2} it has been noticed that changes in the operating mode of the readout electronics can bring clear improvements to the quality of the image without any significant change in the MTF, as normally defined. A simple modification to the LSF is suggested, giving a “detective line spread function” (dLSF), the Fourier transform of which is the detective modulation transfer function (dMTF). For the detectors studied the resulting measure of the resolution is shown to be significantly improved when the readout mode is changed, matching the results of other methods of assessing the resolution of the system.

2 Detectors and Readout

The Siberian Digital Radiographic Device (SDRD) \cite{2, 3, 4} detects X-rays in a Xenon-filled multiwire proportional chamber working at high pressure. It is a linear array of independent sub-detectors, with 320 separate sense wires, 5 cm long and approximately 1 mm apart. To eliminate parallax the wires are aligned along the local direction of the X-ray beam, giving an increase of spacing from 1.20 to 1.25 mm over the thickness of the chamber. Each wire is connected to its own pre-amplifier, which is followed by thresholding and logic circuits that feed into parallel scalers. Every 15 or 30 milliseconds (depending on the version of the device) the contents of the whole set of scalers are transferred to memory to give a single scan line. The detector, the X-ray source and the collimators which limit acceptance are all mounted on a rigid gantry which is scanned transversely at a rate of about 10 cm/sec,
building up a 2-dimensional picture which is stored in RAM.

In the original low resolution standard (ST) version of the device there is one scaler associated with each sense-wire. Because of the finite size of the charge cluster produced by a single X-ray, a significant fraction of all hits gives pulses above threshold on two adjacent channels. A coincidence circuit is provided between each pair of channels to inhibit counts from these double hits. Only channels with single hits are counted for the image.

In the high resolution (HR) version a second set of scalers is provided, one between each pair of wires. Single hits are counted in the wire scalers, as before, but double hits are counted in the extra coincidence scalers, giving a much higher efficiency. The HR system has been shown to resolve significantly finer detail than the ST system, both in laboratory tests [5] and in clinical use [6].

The present work is motivated by the development of a new imaging system, optimised for mammographic examinations, which will use a similar scanning geometry and electronics to the SDRD, but with a different kind of detector, a microstrip gaseous chamber (MSGC) with a strip pitch of approximately 200 micrometres. Although the intrinsic resolution of the MSGCs is expected to be a factor of $\sim 1/5$ of that in the SDRD, the response function of each strip has a very similar shape.

Laboratory tests have been made on test MSGCs with parallel strips, both with Xenon at high pressure and with Argon at atmospheric pressure. On the basis of these tests a computer simulation has been developed which can be used to predict the performance of a high pressure MSGC with the strips tapered towards the X-ray source in the same way as in the SDRD (similar tapered-strip MSGCs are also being developed for the CMS detector at the CERN Large Hadron Collider [7]).
3 Resolutions and Efficiencies

In Figure 1 curve a) shows the simulated response of one MSGC strip when a narrow X-ray source is scanned across it. This represents the line spread function of the linear detector. If the same kind of coincidence electronics is used as in the SDRD, then the LSF is sharpened by the suppression of double hits, as shown by curve b). And if a second set of scalers is provided, as in the HR mode of the SDRD, then an additional LSF can be obtained, representing the response of the coincidence channel as the narrow source is scanned across the detector (curve c). The RMS spreads of the LSFs are shown in the same figure.

Just as with the SDRD, it is possible to consider operating the MSGC device in either the ST mode, with only single hits on strips counted and used in the image, or in HR mode, with an extra set of scalers for the double hits. Figure 2 shows the efficiency of the detector in registering hits from X-ray photons that have converted in its active area $\eta(x)$. Clearly the HR mode makes much better use of the X-rays which reach the detector, hence minimising the dose to the patient. (It appears from Figure 2 that the HR mode can sometimes exceed very slightly 100% efficiency. This is due to the few events in which 3 channels are hit giving two apparent hits from a single event. There is no significant effect on the argument given here.)

The LSFs shown in Figure 1 for the single strip hits and for the coincidences are very similar in width. But an apparent paradox arises if the normal definition of MTF is used to estimate the effective resolution of the chamber in the two modes. In the ST mode one would use the LSF of curve b) on Figure 1. In the HR mode it would be reasonable to take the average of curves b) and c) as the response of the detector (Figure 1 curve d), which means that the predicted MTFs in the two modes would be almost identical. As mentioned in section 2 above, if this is taken to mean identical image
quality it contradicts both laboratory measurements and clinical experience with the SDRD.

4 Definition of the dLSF and the dMTF

The detective line spread function is defined as:

\[ dLSF(x) = \frac{LSF(x)}{\eta(x)} \]  

For the ST system, with rejection of coincidences, the LSF as a function of \( x \) from Figure 1, curve b), is divided by the efficiency \( \eta(x) \) from Figure 2, giving a fatter curve for the dLSF shown as circles in Figure 3 a), (for comparison, the stars represent the unmodified LSF from Figure 1). The corresponding dMTF is obtained by taking the Fourier transform of the dLSF (Figure 3 b). The 10% level on the dMTF gives a resolution of 4.5 line pairs per mm, whereas the unmodified MTF would suggest a resolution of 6.5 line pairs per mm.

In the HR mode the combined relative efficiency of the two kinds of channel remains close to \( \eta(x) = 1 \) for all \( x \), so there is no visible difference between the LSF and the dLSF, shown in Figure 3 c), or between the MTF and the dMTF, shown in Figure 3 d). The resolution at the 10% level of either the MTF or the dMTF is 6.5 line pairs per millimetre.

The detailed shapes of the dLSF and dMTF curves in Figure 3 show that the response of the ST mode resembles the response of a detector with a 200 \( \mu m \) square aperture, while that of the HR mode resembles a Gaussian response with a FWHM of 138 \( \mu m \).
5 Conclusions

The detective line spread function, defined in equation [1], can be Fourier transformed to give the detective modulation transfer function (dMTF) which is a more realistic measure of the true resolution for a detector whose efficiency varies significantly with position within the scale of variations of the LSF. Using the dMTF it is possible to give an objective prediction of the improved performance which can be expected from a Microstrip Gaseous Detector if it is operated in the HR mode, with separate scalers for single-strip hits and for coincidences between adjacent wires. With a strip pitch of approximately 200 $\mu$m the resolution in HR mode is 6.5 line pairs per millimetre whereas, in standard (ST) mode, the resolution would be 4.5 line pairs per millimetre due to significant reductions in efficiency midway between the strips. This result explains the clear improvement in image quality which has been reported for the Siberian Digital Radiographic Device [5] when it was upgraded from the ST to the HR mode.

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**Figure 1.** The simulated LSFs of an MSGC operating at different modes: a) single strip without special electronics; b) single hits; c) coincidences; d) average of b) and c).

**Figure 2.** Comparison of the efficiency of the detector in registering hits from X-ray photons that have converted in its active area for the ST and HR modes.

**Figure 3.** The LSF compared with the dLSF, and the MTF compared with the dMTF for the ST and HR modes.
Figure 1. The simulated LSFs of an MSGC operating at different modes:
a) single strip without special electronics; b) single hits; c) coincidences; d) average of b) and c).

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