MEASUREMENT OF WIENER SPECTRUM OF RADIOGRAPHIC SCREEN-FILM SYSTEMS

WAN MUHAMAD SARIDAN WAN HASSAN*

Abstract.   A method to measure the Wiener spectrum of radiographic screen-film systems in a hospital setting is presented. Radiographs exposed to uniform X-rays are scanned by a microdensitometer, and optical density fluctuation data about the mean density are obtained by subtracting the mean density from the density values. The data are low-pass-filtered by averaging pairs of pixels, followed by low-frequency filtering to eliminate very low-frequency components. A slit trace is synthesised by averaging adjacent traces and the trace is segmented to segments of 256 data points per segment with overlap of 128 data points. Data in each segment are windowed and fast Fourier transformed. The Fourier coefficients are squared and normalized to obtain the power spectrum. On site measurement for Lanex Regular and Lanex Fine screens gives results that are comparable with published data.

Key words: Noise power spectrum, radiography, screen-film system, Wiener spectrum

Abstrak.   Satu kaedah untuk mengukur spektrum Wiener sistem skrin-filem radiografi dalam persekitaran hospital disajikan. Radiograf yang didedahkan kepada sinar-X seragam, diimbas oleh sebuah mikrodensitometer, dan data turun naik ketumpatan optik di sekitar nilai ketumpatan min diperoleh dengan menolak nilai ketumpatan min daripada nilai ketumpatan optik. Data dituras-laluan-rendahkan dengan mempuratakan pasangan piksel, diikuti dengan penurasan frekuensi rendah untuk menyingkirkan komponen frekuensi yang sangat rendah. Suatu surihan celah disintesis dengan mempuratakan surihan-surihan bersebelahan, dan surihan celah itu dibahagikan kepada segmen-segmen 256 data yang bertindih 128 datanya. Data dalam setiap segmen ditingkapkan dan transformasi-Fourier-pantaskan. Pekali-pekali Fourier dikuasa dua dan dinormalkan untuk menghasilkan spektrum kuasa. Pengukuran di lapangan terhadap skrin Lanex Regular dan Lanex Fine memberikan keputusan yang hampir sama dengan hasil yang telah diterbitkan.

Kata kunci: Spektrum kuasa, radiografi, sistem skrin-filem, spektrum Wiener

1.0   INTRODUCTION

In medical radiography, the radiographic noise of a screen-film system may be characterized by the Wiener spectrum (WS) of the screen-film. WS is the noise power spectrum of the optical density fluctuation of the radiograph which was exposed to a uniform X-ray radiation. A method used for the measurement of the WS of the screen-film is the fast Fourier transform digital method [1-3]. The WS is mea-

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sured by scanning an area of a radiograph exposed to a particular uniform density using a long and narrow slit scanning aperture. The data are subjected to digital fast Fourier transform (FFT), and modulus square of the transform amplitudes give the WS.

While there is a considerable literature on WS computation, in practice the best methodology is not clear. The measurement of the WS still remains a complex subject, and is being addressed by Task Group 16 of the American Association of Physicists in Medicine [4]. This paper describes a WS measurement work in a hospital setting at the Aberdeen Royal Infirmary, Scotland, performed by the author.

2.0 METHOD AND MATERIALS

2.1 Experimental Setup

Radiographs at gross optical density of 1.5 were prepared by exposing the screen-films (Kodak Lanex Regular/T Mat G and Lanex Fine/T Mat G, abbreviated as LR/TMG and LF/TMG respectively) with 80 kVp X-ray from a medical x-ray machine, with a 16 mm thick aluminum filter affixed to the X-ray tube window. The focus-to-film distance was 1.5 m. The distance of the screen-film to the floor was 20 cm, to minimize scatter. The set-up attempted to simulate the exit spectrum from human tissue in chest radiography, and the measurement was done in a hospital X-ray room using the facilities in the room. Figure 1(a) shows the geometrical arrangement of the X-ray machine and the screen-film for the measurement.
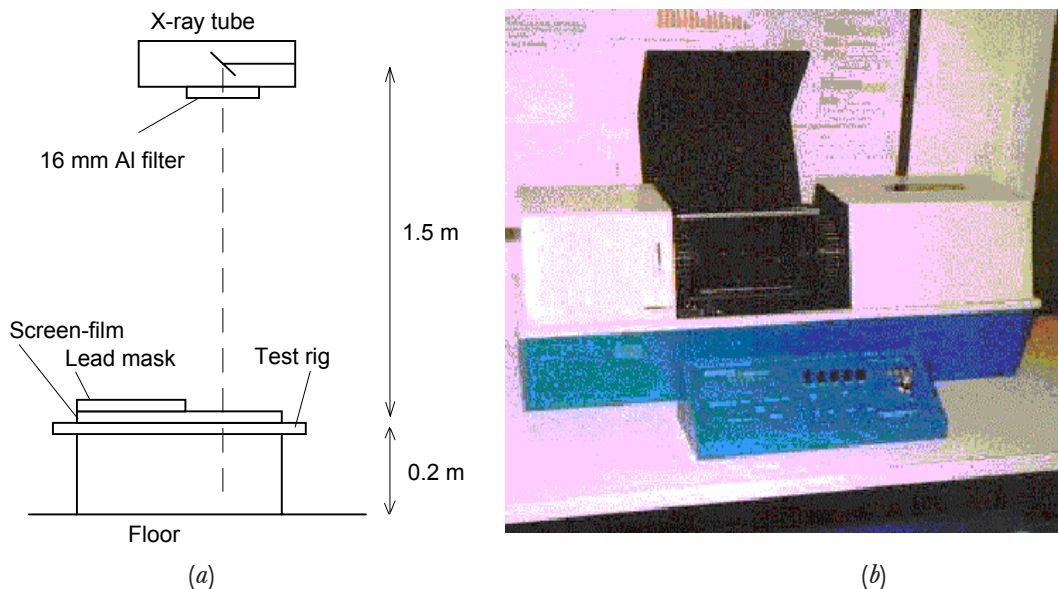

Figure 1 (a) The set-up for the Wiener spectrum measurement, and (b) a picture of the scanning microdensitometer employed in the measurement.

2.2   Radiograph Scanning

An area of the radiograph was scanned by a scanning microdensitometer (Photoscan System P-1000, Optronics International Inc., Chelmsford, Massachusetts, USA), which is a rotating drum device, with a square aperture of side 12.5 μm (Figure 1(b)). The sampling distance for this work was Δx = 12.5 μm. Hence, the Nyquist critical frequency was u_N = $1/2\Delta x$ = 40 mm^{-1}. The size of the scan was 6 000 pixels by 300 pixels which corresponds to a physical area of 75 mm by 3.75 mm, and the 8 bit scan data were saved as a binary PC file. The spatial frequency of interest in medical radio-graphy is in the range of 0-10 cycles/mm, thus the aliasing effect was negligible for this system. Following Doi et al. [3], the length of the FFT was L = 256, hence the spatial frequency interval or the spatial frequency resolution was Δu = $1/L\Delta x$ = 0.3125 mm^{-1}.

2.3   WS Calculation

A computer program was written to calculate the WS from the image matrix file. It synthesizes a slit length by averaging adjacent scan traces. The resulting slit trace was assumed to represent one-dimensional noise data. These data were broken down into overlapping segments which were then subjected to WS calculation via the digital fast Fourier transformation. The calculation of the WS was based on work of Doi et al. [3], Wagner [1], Sandrik and Wagner [2], Cowen and Workman [5], and Press et al. [6]. The description of the program follows.

The program displays the scanned image from which a rectangular region of interest (ROI) could be selected using a mouse. It then converts pixel values data in the ROI to density values and calculates the mean density of the ROI. The mean density is then subtracted from the data. At this point, density fluctuation data of zero mean are ready.

The data are then smoothed or low-pass-filtered by averaging pairs of pixels, according to

$$x_i^{'} = \frac{1}{2} \sum_{j=1}^{i+1} x_j^{''}$$

where $x_i^{''}$ and $x_i^{'}$ are the original and the smoothed data respectively.

The data are then low-frequency-filtered to eliminate very low-frequency components attributed to physical defects in the emulsion layer and roller marks from the film processor. This was done by the algorithm

$$x_i = x_{i+n_l/2}^{'} - \frac{1}{n_l} \sum_{j=i}^{i+n_l-1} x_j^{'}$$

A value of $n_l = 300$ was chosen for the above algorithm based on reproducibility of the results. Hence, x_i is the deviation of x_i' from a local mean that has a range of $n_l = 300$ points.

A slit trace is then synthesized by averaging adjacent traces, i.e., averaging data points in the direction perpendicular to scan direction. The number of data points averaged in that direction is equal to the length of synthesized slit (in mm) divided by sampling interval in the perpendicular direction which was 0.0125 mm. At this point one-dimensional slit trace data are ready.

The data are segmented to overlapping segments of $L = 256$ data points per segment with overlap $L/2 = 128$ data points. The maximum number of segments available depends on the area ROI selected, and this in turns depends on the area of film scanned. Data in each segment are windowed according to

$$a_i = x_i \cdot w_i$$

where

$$w_i = 1 - \left(\frac{i - 0.5(L-1)}{0.5(L+1)} \right)^2, \quad i = 0, 1, ..., L-1$$

is the Welch window [6]. The use of this window in the domain of the data has approximately the effect of the use of the hanning (Tukey) window in the domain of the Wiener spectrum [3].

Each segment of data is then subjected to FFT (of length $L = 256$) to compute its discrete Fourier transform

$$A_m = \sum_{n=0}^{L-1} a_n e^{-2\pi jnm/L}, \quad m = 0, 1, ..., L-1$$

where $j = \sqrt{-1}$. The FFT code used was from reference [6] which is based on the Danielson-Lanczos lemma. The FFT is then squared (i.e. the real and imaginary parts of the Fourier coefficients are squared and added) to get the power spectrum $P(u_m)$, defined at $L/2 + 1$ frequencies as

$$P(0) = P(u_0) = |A_m|^2$$
$$P(u_m) = |A_m|^2 + |A_{L-m}|^2, \quad m = 1, 2, ..., L/2-1$$
$$P(u_N) = P(u_{L/2}) = (A_{L/2})^2$$

where u_m is defined only for the zero and positive frequencies

$$u_m = \frac{m}{L\Delta x} = m\,\Delta u = 2u_N\,\frac{m}{L}\,,\; m = 0,1,...,L\,/\,2$$

and Δx is the sampling interval, $u_N = 1/2\Delta x$ is the Nyquist critical frequency, whilst $\Delta u = 1/L\Delta x$ is the frequency interval or the frequency resolution. Thus, for our case the power spectrum is the one-sided power spectrum [6].

The power spectrum is normalized by multiplying it by $\Delta x/LU$, to give the spectral estimate, i.e.

$$\frac{\Delta x}{LU}\,P\left(u_m\right)$$

where

$$U = \frac{1}{L}\sum_{i=0}^{L-1} w_i^2$$

This normalization is the same as that of Cowen and Workman [5]. The spectral estimates from all the data segments are then averaged.

The resulting spectral estimates, $W''(u_m)$, are corrected for the smoothing that was previously done by

$$W'\left(u_m\right) = W''\left(u_m\right)\left[\frac{2\sin\left(\pi u_m\Delta x\right)}{\sin\left(2\pi u_m\Delta x\right)}\right]^2$$

These spectral estimates are further corrected for the finite slit width b of the scanning aperture, and multiplied by the synthesized slit length l of the scanning aperture to give an estimate of a cross section through the two-dimensional noise power spectrum

$$W\left(u_m\right) = W'\left(u_m\right)l\left[\frac{\pi u_m b}{\sin\left(\pi u_m b\right)}\right]^2$$

The program prints many details of the calculation on screen, e.g., average and variance of the density fluctuations of ROI, values of WS at selected spatial frequencies, areas under WS curves, corrections, and error estimates. It also displays the WS curve on the computer screen.

3.0   RESULTS AND DISCUSSION

Figure 2 shows that the WS of LR/TMG is greater than that of LF/TMG for spatial frequency of 0.3–5.0 cycles/mm. At about 5.0 cycles/mm the WS of both cross each other, and for spatial frequencies greater than 5.0 cycles/mm the WS of LR/TMG is

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less than that of LF/TMG. Our results for LR/TMG and LF/TMG are higher than those for Lanex Regular screen with OG film manufactured by Kodak (LR/OG) and Lanex Fine screen with OG film (LF/OG) measured by Doi *et al.* [3] for 0.1–3.0 cycles/mm, but the results somewhat agree at 3.0–8.0 cycles/mm. The WS of LR/OG and LF/OG also cross each other (at approximately 1.0 cycle/mm). As it is known that the noise property of screen-film systems is dominated by the screen rather than the film, it is encouraging to observe that our results show the same trend in this sense.

The same data subjected to a previously developed software by Cantell [7] in the Department of Biomedical Physics and Bioengineering, University of Aberdeen, produced results that are higher by a factor of about 100. A probable reason for this discrepancy is the inclusion of smoothing, low-frequency filtering, and windowing in our calculation but not in Cantell's. Thus we believe that the present calculation by the software gives a more accurate WS result than the previous one.

Relative standard error (RSE) estimate of a WS value was calculated using a formula given by Sandrik and Wagner [2],

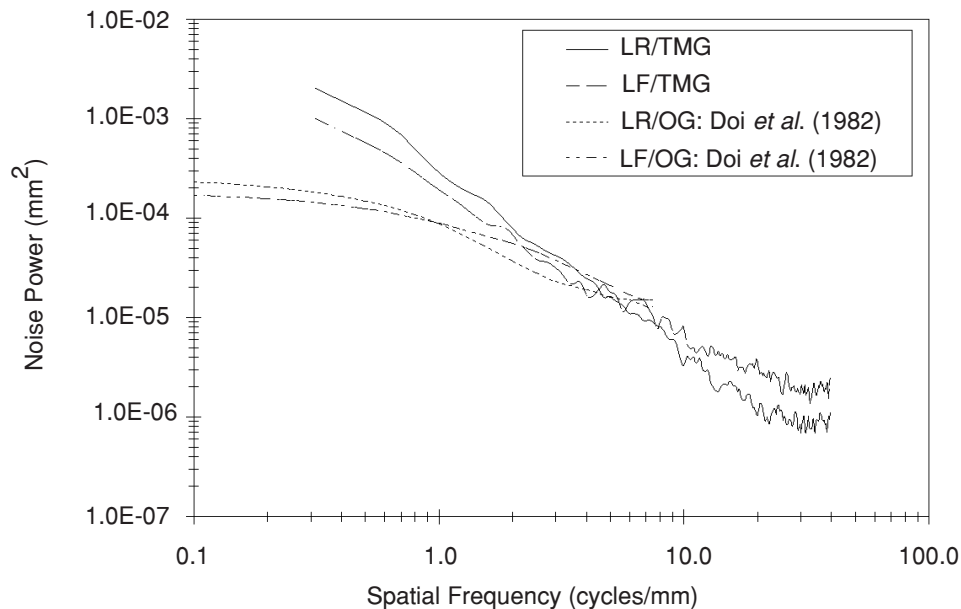$$RSE = \frac{1}{\sqrt{1.4 X \Delta f_w}}$$

Figure 2 Wiener spectrum curve for LR/TMG and LF/TMG measured in this work. The Wiener spectrum curve for LR/OG and LF/OG measured by Doi *et al.* (1982) are also shown for comparison.

where X is the total length of the data record, and Δf_w is the width in the spatial frequency domain of the half power point of the window applied to the data. Applying the result of Welch [8], calculation gives $\Delta f_w = 7/(6L\Delta x) = 0.365$ mm^{-1}. With these values, typical RSE is within 6 to 9%.

4.0 CONCLUSION

A Wiener spectrum measurement system for radiographic screen-film system was developed. Uniformly exposed radiographs are scanned by a scanning microdensitometer, and the scan data are used to calculate the spectrum. The data are low-pass-filtered by averaging pairs of pixels, followed by low-frequency filtering to eliminate very low-frequency components. A slit trace is synthesized by averaging adjacent traces and the trace is segmented to segments of 256 data points. Data in each segment are windowed and fast Fourier transformed. The Fourier coefficients are squared and normalized to obtain the power spectrum. Measurements show that WS curves comparable to published WS curves could be produced.

5.0 ACKNOWLEDGMENTS

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