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Indirect Method of Measurement and Evaluating the Noise Power Spectrum of A Medical X-ray Imaging System

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***Abstract*— The purpose of this paper is to estimate the noise power spectrum by autocorrelation function AFC using a different radiographic film and full field digital mammography. The autocorrelation function is a measure of similarity between a data set and a shifted copy data as a function of shift magnitude. This method has the advantage of providing the value of the noise power at zero frequency and the NPS calculated via autocorrelation function ACF is smoother than NPS, which is calculated by the direct fast Fourier method. Noise power spectrum computations using different images have been attempted using codes written in MATLAB® Version 7.8.0.347 (Math Works, 2009).**

Keywords—Autocorrletion function; Noise power spectrum; Full field digital mammograghy. Fast Fourier Transform FFT

I. INTRODUCTION

Noise is defined as undesirable image characteristics that reduce the visibility of specific objects. Any component of the signal that does not convey relevant information can be considered as noise [1]. Examples of noise are the fluctuations in the source signal, randomness in the detector output, and superimposed structures which are not related to the signal of interest.In general, image quality is determined by three primary physical parameters: contrast, spatial resolution and noise [2]. These quality parameters can be evaluated by objective image quality measurements such as signal-to-noise ratio (SNR), modulation transfer function (MTF) and Wiener spectra (WS). Together they form a basis for the description of image quality, which encompasses the three primary physical image quality parameters; (See Fig 1).

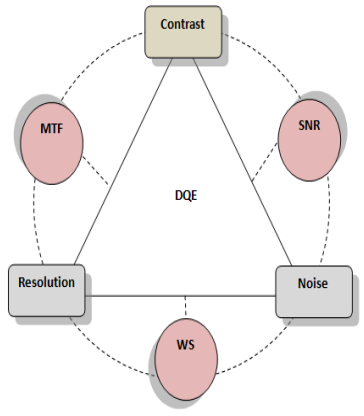

Fig.1 Image quality triangle: illustrates the Wiener spectrum in relation to parameters and physical image measurements [3].

With any imaging system, images are partially degraded by various sources of statistical fluctuation which arise along the imaging chain [4]. For example, quantum and electronic noise that produces random variations of signal can obscure useful information in a diagnostic image. Random noise means fluctuations of the signal over an image, as a result of uniform exposure, and can be characterized by the standard deviation of the signal variations over the image of a uniform object. The Wiener spectrum must be used to get a more complete description of the spatial correlation of noise: it measures noise power as a function of spatial frequency [4][5][6].

The noise power spectrum (NPS) of a radiographic film can be expressed in three constituent noise sources and can be written as

$$W_T(u) = W_Q(u) + W_G(u) + W_S(u) \qquad (1)$$

where W_T, W_Q, W_G, W_S stand for the WS of the system radiographic noise, quantum mottle, film graininess and screen structure mottle respectively, and u is spatial frequency. Radiographic mottle is the fluctuations of film density from one area to another due to imaging system noise [7][8][9][10]. In order to specify the spatial structure of image noise or to describe any correlation between the densities at different points, the autocorrelation function of the fluctuation could be used [11].

Development in medical imaging systems has led to new sources of noise and new ways to address and minimize their impact on the quality of the image. As a digital detector, the measured noise power spectrum will suffer from aliasing because the noise data might have been sampled at discrete intervals by the pixel matrix. Williams et al (1999) discuss aliasing of NPS for digital mammography systems [12]. Detectors that produce images with significant spatial frequency content above the sampling limit prior to sampling will suffer from aliasing. Ultimately, aliasing leads to an increase in noise power at high spatial frequencies [13].Some of the important theoretical aspects of noise power measurements are in the work of Cunningham [14,15] and Dobbins III (2000)[16].

The most economical way of estimating the autocorrelation for a given noise image is first to estimate the noise power spectrum and then calculate its inverse of fast Fourier (FT) [17]. Since the autocorrelation function may be calculated from the noise power spectrum, and vice versa, both of these methods provide equivalent and complete descriptions of the corre1ations present in the noise. In this study calculation of

WS via autocorrelation function offers significant advantages over the standard method by improving the accuracy with which the WS is determined and by allowing the NPS at zero frequency to be determined in a straightforward manner by using a radiograph film and full field digital mammography systems.

II. BEUTEL'S METHOD

This method has the advantage of providing the value of the noise power at zero frequency and NPS calculated via autocorrelation function (ACF) is smoother than NPS, which is calculated by the direct (FT) method [18]. The formula for computing autocorrelation function (ACF) is

$$AFC(x_k) = \frac{1}{N^2}\sum_{K=0}^{N-1}\sum_{i=j=1}^{N} D_i D_{i+k,j} \qquad (2)$$

A uniformly exposed radiograph is scanned by a microdensitometer, and optical density fluctuation data about the mean density is obtained by subtracting the mean density from the density values. Total N density values, each spaced by dx = 0.0125mm (sampling interval) are chosen. The density values D_i were low pass flirted to provide protection against aliasing .The first N points on the autocorrelation function are calculated using Equation 2.

III. METHODOLOGY

The autocorrelation function is a measure of similarity between a data set and a shifted copy data as a function of shift magnitude. Correlation analysis is used to find periodic patterns in noisy data. The definition of autocorrelation function (ACF) is similar to that for the auto covariance function (ACVF). The auto covariance function estimator for record of N data point's x_i is given by

$$C_{xx}(k) = \frac{1}{N}\sum_{i=1}^{N-K} x_i . x_{i+k} \qquad (3)$$

That is, for a given shift (or lag) of the record along itself, k, the ACVF $C_{XX}(k)$ is a summary of how well the shifted data resembles the unshifted record [17]. Noise power spectrum computations using different images have been attempted using codes written in MATLAB® Version 7.8.0.347 (Math Works, 2009). Fig2 shows the steps of calculating NPS by Matlab codes using different a radiograph film and full field digital mammography systems In this work images A1.bmp and A3.bmp are digitized images obtained from analog images by scanning. The uniform background area of the film was scanned by a microdensitometer. This scanning gave image A1.bmp and A3.bmp. The size of the scan was 1000×1000 pixels corresponding to the physical area of 1.25cm by 1.25cm and 978×590 pixels corresponding to Images file0000.bmp, file0001.bmp and file0002.bmp are full field digital mammography systems. Images A1.bmp and A3.bmp were prepared at the Aberdeen Royal Infirmary, Scotland. Images file0000.bmp, file0001.bmp and file0002.bmp were prepared at Putrajaya Hospital, Malaysia.

IV. RESULTS AND DISCUSSION

A. Low Pass Filter

In Beutel's method, the data is low–pass filtered by averaging pairs of pixels; this is similar to the Wagner method. Using low pass filtering it was found that the noise power spectrum in the high frequencies is reduced as in Fig.3.

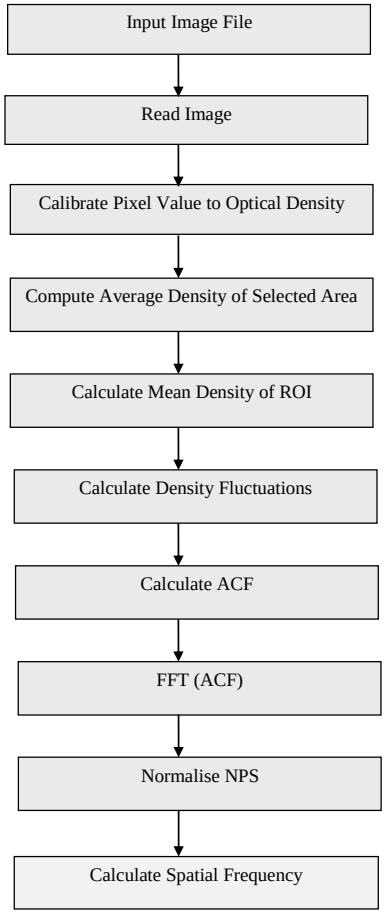

Fig2.Block diagram describes steps to compute the NPS by Beutel's method.

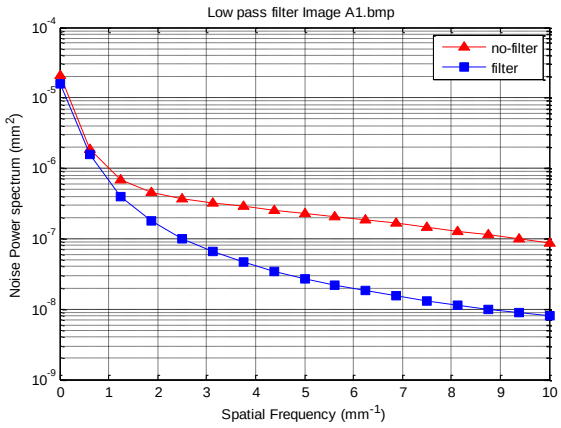

Fig. 3 NPS values were measured with low pass filter and without filter.

B. Length of fast Fourier transform

Fig.4 illustrates the effects of changing the fast Fourier transform FFT length (L) upon the NPS from different regions of interest ROI$_S$. Table 1 shows different FFT segments. It was found that increasing FFT lengths caused a reduction of segment numbers and reduced the spatial frequency resolution without changing curve shapes.

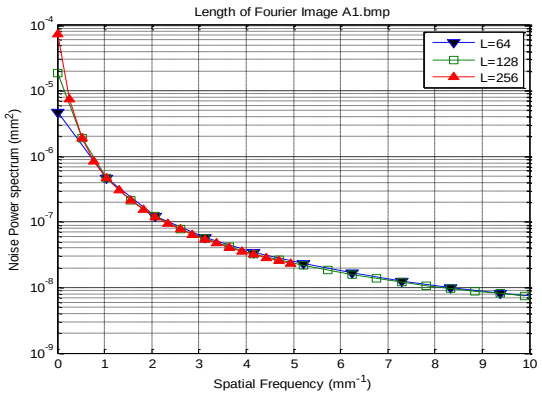

Fig. 4 Comparison among of NPS curves with different values of the length of Fourier transform

TABLE 1**:** Effect of fast Fourier transform length in the NPS curves in Fig. 4**.**

L	No of segments	Area (mm^2)
64	255	1.527xe^{-005}
128	49	3.021xe^{-005}
256	9	6.008xe^{-005}

C. Data Shifting Factor K

We conducted experiments to study NPS by changing the shifting factor *k* in Equation 2 on both digital (file 0000.bmp, file 0001.bmp) and analogue (A1.bmp, A3.bmp). We found that digital images give better results as shown in table 2, Fig.5 and Fig.6. After the change Equation 2 becomes as follows

$$AFC(x_k) = \frac{1}{N^2}\sum_{K=0}^{N-1}\sum_{i=j=1}^{N} D_{ij}D_{i,j+k} \qquad (4)$$

Calculation of NPS by this equation was made using images A1.bmp and A3.bmp. It was found that there is no change in the NPS as in Fig.5 and Fig.6. For digital images (file0000.bmp, file0001.bmp) it was found that there is change as in Fig.7and Fig.8.

TABLE 2: Testing (k) factor used several different images.

Equation	$AFC(x_k) = \frac{1}{N^2}\sum_{K=0}^{N-1}\sum_{i=j=1}^{N} D_{ij}D_{i,j+k}$			
Image	**Factor(k)**	**No. of segments**	**Area (mm^2)**	**L**
A1.bmp	(i+k, j)	49	3.0216e^{-005}	128
A1.bmp	(i , j+k)	49	3.0216e^{-005}	128
A3.bmp	(i , j+k)	28	3.0216e^{-005}	128
A3.bmp	(i+k, j)	28	3.0216e^{-005}	128
File0000.bmp	(i+k, j)	475	3.2851e^{-005}	128
File0000.bmp	(i , j+k)	475	3.1708e^{-005}	128
File0001.bmp	(i+k, j)	475	3.3508e^{-005}	128
File0001.bmp	(i , j+k)	475	3.2103e^{-005}	128

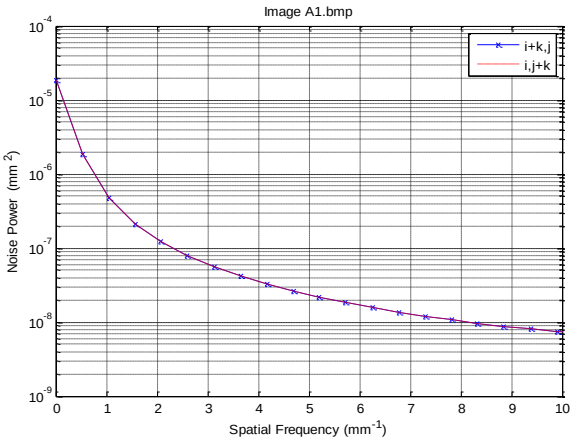

Fig.5 Comparison NPS values between two versions of factor (k) using image A1.bmp.

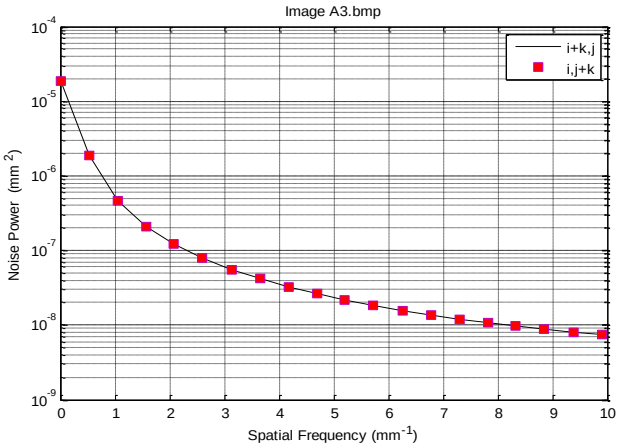

Fig.6 Comparison NPS values between two versions of factor (k) using image A3.bmp.

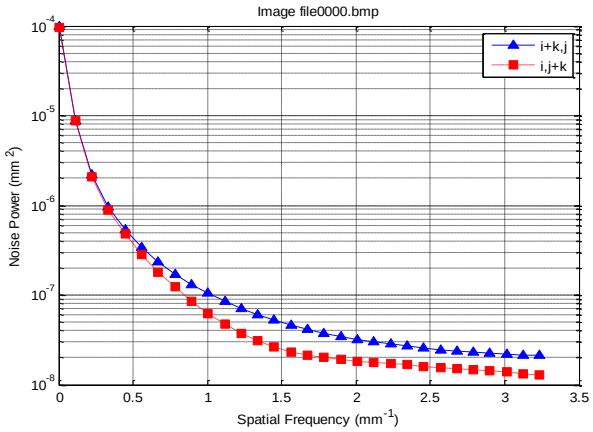

Fig. 7 Comparison NPS values of two versions of factor (k) using image file 0000.bmp.

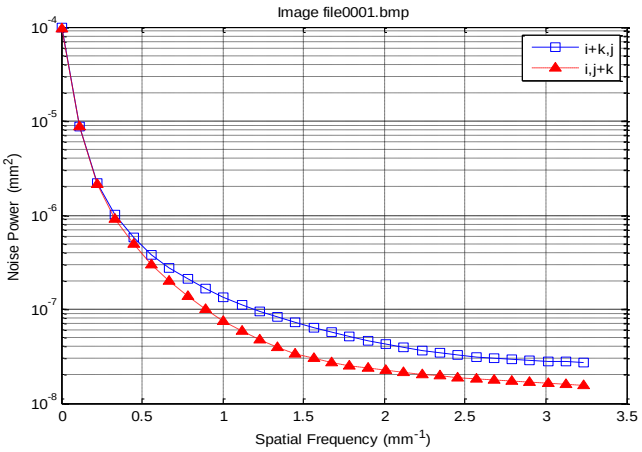

Fig.8 Comparison NPS values of two versions of factor (k) using image file 0001.bmp.

D. NORMALIZATION

In Beutel's method the normalization was reduce to *dx/L* without using any windowing. This was achieved by multiplying the square of the FFT with *dx/L*. As in Fig.9, when this normalization was used, we found the variance of density fluctuation equaled the area under the NPS curve and the order of magnitude of NPS obtained was 10^{-3} to 10^{-5} mm^2. This result would be acceptable in practice.

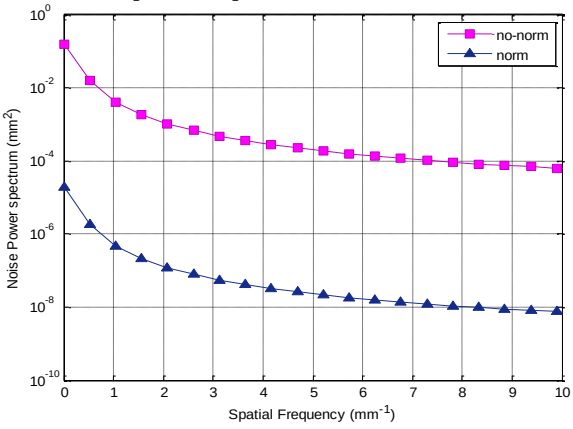

Fig. 9 Normalization the NPS measured via ACF.

III.CONCLUSION

In Beutel's method, the noise power spectrum was measured via autocorrelation function AFC. The AFC is a measure of similarity between data and shifted data as a function of shifted magnitude. The data was subjected to a low-pass filter by averaging pairs of pixels; this filter was based on Wagner's method. It was found that the NPS in the high frequencies is reduced. For the effects of changing fast Fourier length, it was found that increasing FFT length resulted in a reduction of segment numbers and a corresponding reduction in the spatial frequency resolution without changing curve shapes as presented in Table 1 and Fig. 4 respectively. We conducted experiments to study NPS by changing the shift factor *k* in Equation 2 on both digital and analogue images. We found that digital images give better results. The normalization of NPS was achieved by multiplying the square of the FFT with *dx/L* without using any windowing. It was found that the variance of density fluctuation equaled the area under the NPS curve and the order of magnitude of NPS obtained was 10^{-3}-10^{-5} mm^2.

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BIOGRAPHIES

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