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MEASUREMENT OF RANDOM AND PERIODIC IMAGE NOISE IN RASTER-WRITTEN IMAGES

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We generally characterize random image noise by the Wiener spectrum. Most raster written images, however, also contain one-dimensional periodic fluctuations due to the reconstruction of the image from discrete raster lines. The Wiener spectrum measurement is corrupted by these periodic noise components and results cannot be interpreted in terms of density fluctuations. If the Wiener spectrum estimate can be interpreted as a function of the periodic noise, it can be used to measure, for example, rastering and banding.

When images are sampled and reconstructed they are subject to two types of aliasing <1>. This can occur when either the original image or the reconstruction function is not bandlimited. In the first case signal components at higher frequencies are aliased at lower frequencies when the image is sampled. The second type of aliasing, of concern here, occurs when low frequency components of the sampled signal are aliased at higher frequencies during interpolation. Rastering is an example of this second form of aliasing where the 'zero frequency' mean signal is aliased at the sampling frequency, 1/Y, where Y is the raster spacing. The output exposure image is the desired constant plus a cosine signal. During raster scanning and printing periodic image noise can also be introduced by such sources as beam power fluctuations or line position errors <2>.

IMAGE NOISE MEASUREMENT

The one-dimensional Wiener spectrum can be measured in several ways; however, we will discuss the direct estimate via the block ensemble method <3,4>. To estimate the Wiener spectrum, the density trace is divided into several blocks and the discrete Fourier transform of each block is computed. The square of the modulus is then averaged at each frequency for all blocks. The estimate calculation is

$$\widetilde{WS}(j) = \frac{L\Delta x}{N} \left\langle \left| \sum_{n=1}^{N} D(n)\, e^{-ij2\pi n/N} \right|^2 \right\rangle$$

where < > is the ensemble average and | | indicates the modulus of a complex number. The measuring slit length is L, Δx is the sampling distance (in either x or y direction), and N is the block length. Note that in order to estimate the Wiener spectrum the mean density value must be accounted for. If this is not done, the zero frequency estimate has a positive bias of $L\Delta x N\bar{D}^2$

(see ref. 4 for details), where $\bar{D}$ is the mean optical density. Here we are neglecting the effects of the finite block or 'window', which implies a relatively flat Wiener spectrum or a long block length.

Now consider the Wiener spectrum measurement of a random process that contains an additional periodic component. If there is a one-dimensional sinusoidal signal present in the data, this corrupts the Wiener spectrum estimate. Given an additional signal

$$A \cos(2\pi y f) \ ,$$

this results in a positive bias

$$\frac{N \, L \, \Delta x \, A^2}{4}$$

at the frequency f. Thus the amplitude of the Wiener spectrum estimate at the frequency f is the estimate of the random process plus a term which is a function not only of the sinusoidal amplitude but also L, Δx, and N. What this means is that if we choose a different value of, say, N, the block (FFT) length, we change the estimate at f. This does not happen for a purely random noise signal, since WS converges to the true spectrum for large N.

The above bias term of the Wiener spectrum estimate occurs because periodic signals are not described by the power density spectrum (Wiener spectrum) in the same way as random signals. This is due to the discontinuous nature of their Fourier transform <5>. The measured spectrum is the summation of two components

$$\widetilde{WS}(f) = WS_r(f) + \frac{L \, N \, \Delta x \, A^2}{4} \ .$$

In many cases the Wiener spectrum estimate will be dominated by the second term since $L\Delta xN$ is often $> 10^4$. The amplitude, A, is given by

$$A = \left[\frac{4 \, \widetilde{WS}(f)}{L \, \Delta x \, N} \right]^{1/2} \ .$$

In those cases when the true (random) Wiener spectrum, $WS(f)$, is on the order of $(L \, \Delta xN)/4$, it can be estimated from measured values close to f and subtracted:

$$\widetilde{WS}_p = \widetilde{WS}(f) - \widetilde{WS}_r(f)$$

so

$$A = \left[\frac{4 \tilde{W} S p}{L \Delta x N} \right]^{1/2}$$

COMPUTED EXAMPLE

The measured Wiener spectrum from a commercial laser printer image written on silver halide film at a mean density of 1.37 is shown in Figure 1. The measurement made in the slow scan direction shows a rastering component at 10 cy/mm, corresponding to the raster spacing of 0.1 mm. At this frequency the measured value of 3.71 x 10^3 $D^2 \mu m^2$ is much larger than the random spectrum, so we use eq. 1 to find the amplitude. The measurement parameters were:

aperture length = 12.15 mm

sampling interval = 0.02 mm

block (FFT) length = 256 points

The calculated density amplitude is 0.015, giving a peak-to-peak value of 0.031.

The raster ripple was measured independently, using a sampling aperture of 0.59 x 0.01 mm and a sampling distance of 2 μm. Several scans were averaged to synthesize a long aperture to reduce the effects of the random image noise. From these data a direct estimate of the peak-to-peak density fluctuations was 0.030. This can be considered excellent agreement, since the measurements were made on approximately but not exactly the same image area.

CONCLUSIONS

The Wiener spectrum can be used directly to measure random image noise and also indirectly to measure periodic noise. The measurement can be related to periodic rastering and banding only after the measuring aperture length, scan length and sampling interval are considered. We have addressed the case of a process which is the sum of random and periodic components. A sample calculation of rastering via this method agreed with a direct measurement to within 3.3%. Direct measurement of small signal periodic components in random noise is usually more tedious than the Wiener spectrum unless a scanning aperture several millimeters long is used. Although periodic image noise can be measured via the Wiener spectrum, it should be interpreted and specified separately from random noise. This is especially true for one-dimensional signals that have been considered here.

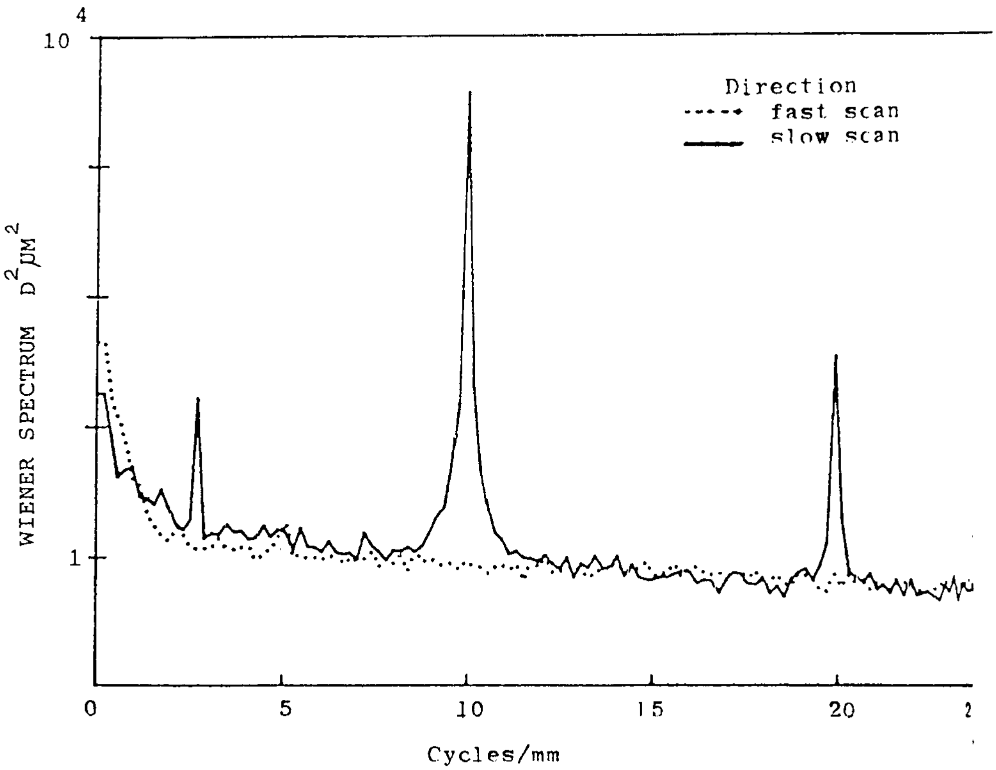

Figure 1. Measured Wiener spectrum for laser printer image.

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