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NOISE REQUIREMENTS FOR THE RECORDING MEDIUM OF A LASER PRINTING DEVICE

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The requirements for a recording process as the final element in an imaging system are usually expressed in terms of its signal-transfer and noise characteristics. The signal-transfer properties may be specified in terms of the macroscopic (gamma) and microscopic (MTF) characteristics, and the noise by the Fourier spectrum of the fluctuations (Wiener spectrum). In general there will be both separate and joint specifications for these components of image quality, where the joint properties may be defined in terms of familiar metrics based on signal-to-noise ratio, such as information capacity or noise equivalent input.

For the specific case of a laser printer as the output device for an electronic imaging system the use of a raster/pixel writing scheme will place further constraints on the final image, but these actually may simplify the choice of recording process. For example, the signal-transfer characteristics of the writing scheme may dominate those of the recording process, and the design of the writing scheme usually involves the trade-offs between MTF optimization and the minimization of artefacts such as aliasing and rastering. This then leaves the noise characteristics of the recording process as the key image quality system variable, assuming relatively straightforward macroscopic speed and gamma properties can be satisfied.

Information theory provides a natural way to define an acceptable level for noise characteristics of the recording process. For discrete information recording, the information capacity can be expressed as

$$C = P \log_2 M$$

where P denotes the number of pixels per unit area, and M is the number of distinguishable recording levels per pixel. Since P is defined by the pixel size (say 100 x 100 μm^2 for a typical laser printer), the noise level of the recording process must be low enough to yield a value of M which will then lead to the desired information capacity. An example of this approach was provided in early work by Altman and Zweig <1>. A parallel approach expresses the output noise in terms of the noise equivalent input, and this is particularly convenient when the input is quantum limited and the output can be expressed in terms of the noise equivalent number of quanta <2>. This approach is appropriate here, since we are concerned with the case where the laser printer is the final stage of a medical imaging system, and the hardcopy record takes the place of a conventional radiograph. In this case established image requirements for radiographs can be translated into specifications for the recording medium.

Let us assume that at the primary (x-ray capture) stage the required upper exposure level corresponds to Q absorbed x-ray quanta per unit area, and that this translates into q quanta per pixel in the hardcopy output. If we assume that the primary imaging medium faithfully records each of the Q quanta (i.e., has a DQE approaching 100%), then the task is to reproduce this number of quanta without degradation. This requires that the output NEQ be not significantly less than Q. The problem is parallel to that of a simple conventional two-stage negative-positive system. Given that we know the image quality of the negative (camera stage), the properties of the positive (print stage) are usually designed to maintain this quality without further appreciable degradation.

We can take the example further by assuming that each of the captured q quanta per pixel are mapped out in the recording process by n imaging particles, with variance in this number such that there is in effect only a very small chance of confusing xn recorded quanta with (x+1)n quanta. A total of

$$N = qn$$

imaging particles per pixel would be required. At peak DQE levels for a conventional screen-film system, around 20 image grains can be made developable per absorbed x-ray quantum, since the influence of the recording film on the system DQE is then very small. Such a value gives us an indicator of an appropriate value for n.

Assuming that the imaging process (silver halide or unconventional) has a macroscopic Nutting-type relationship <3> between maximum density and number and size of particles, then

$$D_{max} = (\log_{10}e) \frac{NZa}{A}$$

where A denotes the pixel area, a is the geometrical particle cross-section area (assumed constant), and Z is the factor relating this area to the area effectively contributing to image density. Then

$$D_{max} = (\log_{10}e) \frac{qnZa}{A} \quad .$$

Assuming that for typical imaging processes (either silver halide or electrophotography) $Z = 1/(\log_{10}e)$, we arrive at

$$a = \frac{D_{max} A}{qn}$$

For values of $D_{max} = 2$, $A = 100 \times 100\ \mu m^2$, $q = 5000$, and $n = 20$, this leads to a value of $a = 0.2 \mu m$ or a diameter of $0.5 \mu m$. This value can now be checked according to a simple Siedentopf/Wiener spectrum model <2,4>. The Wiener spectrum value due to the image particles, $WS(0)_p$, is

$$WS(0)_p = (\log_{10} e)\ ZaD \quad .$$

Then at a density of 1 ,

$$WS(0)_p = a = 0.2\ \mu m^2 D^2$$

while the total output noise, WS (0), will be approximated <5> by

$$WS(0)_o = (\log_{10} e)\ nZaD$$

and hence at a density of 1,

$$WS(0)_o = 20\ a = 4\ \mu m^2 D^2$$

This latter value is around an order of magnitude lower than output noise levels (quantum mottle) for conventional screen-film systems <6,7>. This is reassuring, since the observed noise levels of the latter are known to be a limitation to the viewer.

Less stringent demands on the recording process would of course lead to higher permissible noise levels. For example, let $n = 5$ and $q = 2000$. This could be due to a detector with a DQE of 40% or fewer absorbed x-ray quanta. The particle diameter is now 1.6 μm, and corresponding Wiener spectrum values are $WS(0)_p = 2\ \mu m^2 D^2$ and $WS(0)_o = 10\ \mu m^2 D^2$.

For applications other than for the hardcopy representation of radiographs, considerably less stringent demands might be appropriate. However, we have demonstrated the general methodology for the specification of noise levels in terms of a simple information theoretic approach and have translated this into simple particle models for the recording medium. The values of particle diameter calculated here in the region of 0.5 to 1.6 μm probably represent a reasonable indication of the appropriate size range. Leaving aside considerations of process speed and gamma for laser recording, this range is normal for silver halide processes but poses a more difficult technical problem for electrophotography.

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