nm/PRELIMINARY NOTE

A DIGITAL RATEMETER SYSTEM FOR RECTILINEAR SCANNING

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Traditionally rectilinear scanners have been constructed to achieve film contrast enhancement by using the d-c signal from an analog ratemeter to modulate the intensity of the light exposing the film. Certain effects on the scan arise from such an arrangement which are a result of the exponential response of the analog ratemeter. These effects include degradation of the overall frequency response of the system and a phase shift which results in a spatial lag between the object or source distribution and the recorded image distribution (*1*). This work is concerned with the influence on the above effects of modulating the light intensity with a digital ratemeter rather than an analog ratemeter.

DEVELOPMENT OF MTF FOR DIGITAL RATEMETER

The first step was to determine whether or not there was any theoretical basis for the superiority of the digital ratemeter. This was done by comparing the calculated frequency response functions or the modulation transfer functions (MTF) of the two types of ratemeters.

Frey (*2*) and Gapalo Rao (*1*) have derived the following expression for the MTF of an analog ratemeter;

$$(\mathrm{MTF})_A = \frac{1}{[1 + (2\pi f v RC)^2]^{1/2}} \qquad (1)$$

in which the subscript A refers to the analog ratemeter, f is the spatial frequency of the input signal, v is the detector velocity and RC is the ratemeter time constant.

The MTF for the digital ratemeter was derived as follows: Assume a sinusoidal spatial input distribution; then

$$I(x) = I_0 + I'_0 \cos 2\pi f x \qquad (2)$$

in which $I(x)$ is the amplitude of the distribution function at any point x, I_0 is the average value of I, I'_0 is the amplitude of modulation of I, f is the spatial frequency of I and x is the spatial variable. Now let $C(x_n)$ equal the number of pulses recorded by the digital ratemeter during the nth averaging period. Then

$$C(x_n) \propto \int_{x_{n-1}}^{x_n} (I_0 + I'_0 \cos 2\pi f x) \frac{dx}{v}$$

in which v is the detector velocity and x_{n-1} and x_n are the respective values of x at the beginning and end of the nth averaging period. Integrating,

$$C(x_n) \propto \frac{1}{v}\left[I_0(x_n - x_{n-1}) + \frac{I'_0}{2\pi f}(\sin 2\pi f x_n - \sin 2\pi f x_{n-1})\right]. \qquad (3)$$

Now let Δx equal $x_n - x_{n-1}$ or the distance the detector moves during the averaging period Δt. Also let $B(x_n)$ equal the intensity of the light flashes for the interval $x_n < x < x_{n+1}$. Since $B(x_n)$ is proportional to $C(x_n)$, it follows that

$$B(x_n) \propto \frac{1}{v}\left[I_0 \Delta x + \frac{I'_0}{2\pi f}(\sin 2\pi f x_n - \sin 2\pi f x_{n-1})\right]. \qquad (4)$$

Now choose $B(x_n)$ to be maximum when $x = 0$. Then the minimum values of $B(x_n)$ occur when the center of the averaging interval (x_c) corresponds to the values of $2\pi f x_c$ equal to odd integer multiples of π. Similarly the maximum values of $B(x_n)$ will occur when $2\pi f x_c$ is equal to even integer multiples of π. Substituting and simplifying,

$$B(x_n)_{max} \propto \frac{1}{v}\left(I_0 \Delta x + \frac{I'_0}{\pi f} \sin \pi f \Delta x\right), \qquad (5A)$$

$$B(x_n)_{min} \propto \frac{1}{v}\left(I_0 \Delta x - \frac{I'_0}{\pi f} \sin \pi f \Delta x\right). \qquad (5B)$$

The output contrast (m_0) is defined as

$$\frac{B(x_n)_{max} - B(x_n)_{min}}{B(x_n)_{max} + B(x_n)_{min}}. \qquad (6)$$

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Substitution of Eq. 5 into 6 yields

$$m_0 = \frac{I'_0}{I_0}\frac{\sin\pi f\Delta x}{\pi f\Delta x}. \qquad (7)$$

Since the input contrast (m_i) is equal to $\frac{I_0}{I'_0}$ (from the defined input distribution function), and since

$$MTF = \frac{m_0}{m_i},$$

it follows that

$$(MTF)_D = \frac{\sin\pi f\Delta x}{\pi f\Delta x}$$

in which the subscript D signifies the digital ratemeter. This result is the same function as that obtained by Frey for the MTF of a rectangular light spot used in scan photorecording (*2*). The two arguments are identical mathematically.

The calculated frequency responses of the two systems were then compared on the basis of equal statistical uncertainty in an instantaneous reading. This condition is met when

$$\Delta t = 2RC,$$

in which RC is the time constant of the analog ratemeter and Δt is the averaging time for the digital ratemeter.

The calculated curves are shown in Fig. 1. The abscissa is the reciprocal of the number of averaging intervals the digital ratemeter completes in a distance equal to one wavelength of the input signal. In scanning, the range of interest is around 10–20 averaging intervals per wavelength. This corresponds to about 0.05–0.10 on the abscissa of the curves in Fig. 1. The MTF for the digital ratemeter is higher than that for the analog ratemeter in the range of interest. The difference is small, however, because both curves approach 1 as the source frequency approaches zero.

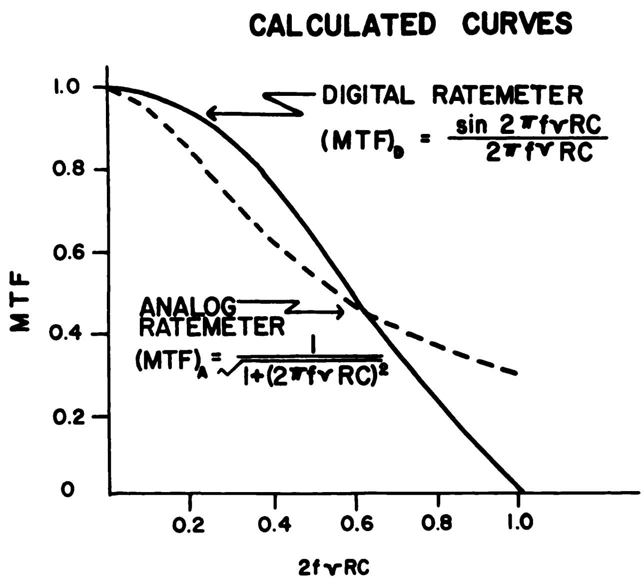

FIG. 1. Calculated curves of MTF as function of 2fvRC for analog and digital ratemeters.

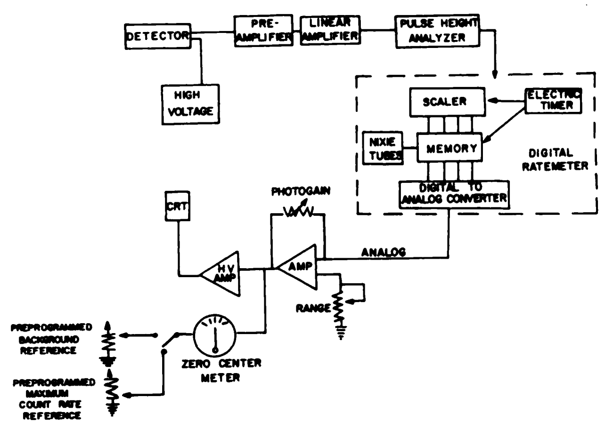

FIG. 2. Simplified block diagram of rectilinear scanner controlled by digital ratemeter.

EXPERIMENTAL APPROACH

On the basis of the foregoing analysis, a Picker rectilinear scanner in our laboratory was modified to include a digital ratemeter*. The digital ratemeter consists of a 3-decade scaler, a buffer memory with indication, a digital-to-analog converter and an electronic timer. The operating time is preset on the electronic timer providing incremental control for the scaler. The scaler is reset and turned on for the preset time period, and upon expiration of the time period the counts from the scaler are transferred to the buffer memory. The memory provides both external indication via Nixie tubes and the logic information to the digital-to-analog converter. Upon command of memory the scaler is again reset by the electronic timer and the next time period begins. The buffer and reset time of the scaler is less than 1 μsec; therefore, real-time operation is provided without significant data gaps in the information flow.

The digital-to-analog converter consists of a current summing network which provides a digitally weighed analog summation to allow an accurate analog output for the digital information in the memory. Since the memory is held during the counting period of the succeeding cycle, the analog output resembles a histogram. The analog output from the digital ratemeter is connected to an operational amplifier. The

* Manufactured by Hunkar Instrument Development Laboratory, Cincinnati, Ohio. (Other commercially available digital ratemeters may be adapted for use in this system.)

range and photo-gain controls are used to preset the conditions for an optimum optical density on the scan. The photo-gain is adjusted to an arbitrary initial condition. Then, with the detector over a background area, the range potentiometer is adjusted to offset the operational amplifier to a degree that is equivalent to the voltage on the background reference potentiometer. The balances are indicated by a zero center meter. The detector is then positioned over the maximum counting rate and the photo-gain is adjusted to again give a null reading on the zero center meter. Hence the cathode-ray tube (CRT) voltage is optimized for maximum counting rate conditions. The output of the operational amplifier is connected to a high-voltage amplifier which drives the CRT.

The scan speed is determined as follows: with the probe over the area of maximum counting rate, the averaging time of the digital ratemeter is adjusted until the number of counts per interval necessary to give the desired number of counts per cm^2 on the scan are observed. The number of averaging intervals per centimeter is established beforehand to correspond to the maximum source frequency of interest (8–10 averaging intervals per centimeter appear optimum for most scans). The scanning speed is then a function of the averaging time alone.

RESULTS

Scans performed in our laboratory on the same patient using both digital and analog ratemeter scanners show little discernible difference in scan quality when both instruments are set up and operated properly. It has been observed, however, after studying a number of thyroid scans, that unsatisfactory scans due to improper setting up of the scanner were significantly fewer in scans performed on the digital ratemeter scanner. Thus, in addition to the small increase in frequency response, the digital ratemeter affords easier optimization of scanning parameters where contrast enhancement is used with less chance for human error in setting up the scanner.

REFERENCES

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