JOURNAL OF NUCLEAR MEDICINE 7:501-509, 1966

A Rescanner with Photographic Color Readout[1]

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INTRODUCTION

The use of an averaging light intensity meter in the extraction of information from scan records has been reported previously (1,2). This device, called a "rescanner", was used as a sort of scanning densitometer and it showed some ability to extract from scan records information that might have been missed with the unaided eye.

In the original device, the output of a light sensor (which looked at a light source through the record being analyzed) was converted to a train of pulses whose frequency varied logarithmically with record opacity. These pulses were used to produce a "rescan" record from ordinary scanner recording systems. The system is actually an analog computer, since it integrates recorded information over a definite area.

Although the original rescanner produced some interesting and even spectacular results, it lacked the ability to show quantitatively the opacity, or average counting rate, in the region of the original scan record seen by the sensor. Thus, the capability of the system as a computer was impaired because of readout limitations.

A new device was constructed, using a photographic color readout, to remove some of the limitations of the older method.[5] The new readout is an isoopacity contour map of the original scan; the contours are formed by the boundaries of the color regions.

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[5]The concept of operation and the necessary electronic circuits for the device were developed at ORNL; the construction of the mechanical system was carried out at ORAU under Kimble's direction. The calibration, evaluation, and development of the color arrangements were done entirely by Uchiyama, also at ORAU.

METHOD AND DESIGN CONSIDERATIONS

The new method differs from the first in that the light sensor (a silicon photodiode) is operated in a linear, or short-circuit current, mode. In addition, the output of the system is a voltage instead of a pulse rate. Finally, the output voltage is transformed into angular displacement of a wheel of color filters. A stationary camera with Polaroid color film, views a steady light through whatever filter is presented by the wheel. The color wheel, its light source, the sensor and the associated electronic circuits are all moved together in front of the camera in an ordinary rectilinear scanning motion. As the sensor is thus moved over the original scan record, a color picture accumulates on the film in the camera.

Though developed independently, the color photorecording is seen to be akin to that reported by Adams and Jaffee in 1964 (3). The color wheel is driven by a dc servomotor; the solid-state servo system uses a novel optical position-feedback method that reduces servomotor torque requirements and provides higher speed.

The system is shown in block diagram in Figure 1. Light from the source under the original scan record falls on the sensor. Current from the sensor is

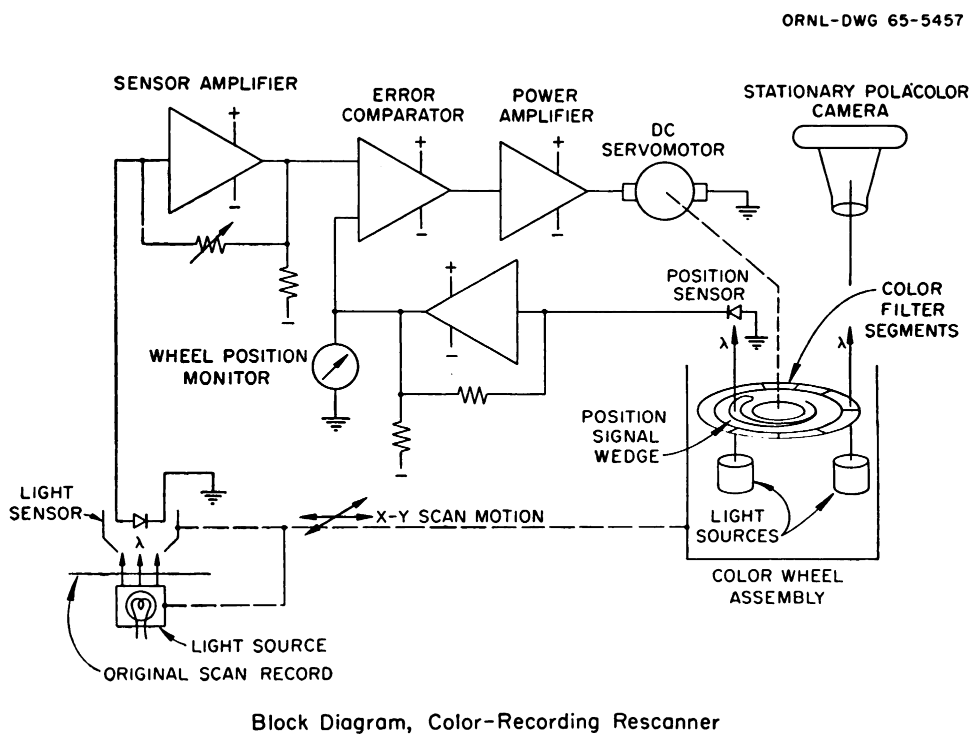

Fig. 1. Block diagram of the color-recording rescanner. The color wheel assembly is mechanically attached to the light sensor that reads the original scan record.

converted into a voltage appearing at the output of the sensor amplifier. This voltage is compared to another voltage signal that corresponds to the position of the color wheel. If there is a difference between the voltages, the power amplifier drives the motor, and color wheel, until the difference is minimized. Thus, the current output of the sensor is translated to an angular position on the color wheel.

This is a standard position servo system except for the means used to derive a signal corresponding to the position of the color wheel. The usual means chosen is to drive a potentiometer linked to the color wheel. The motor used in early trials did not deliver enough torque to accelerate properly when coupled to the lowest-torque potentiometer available at the time.

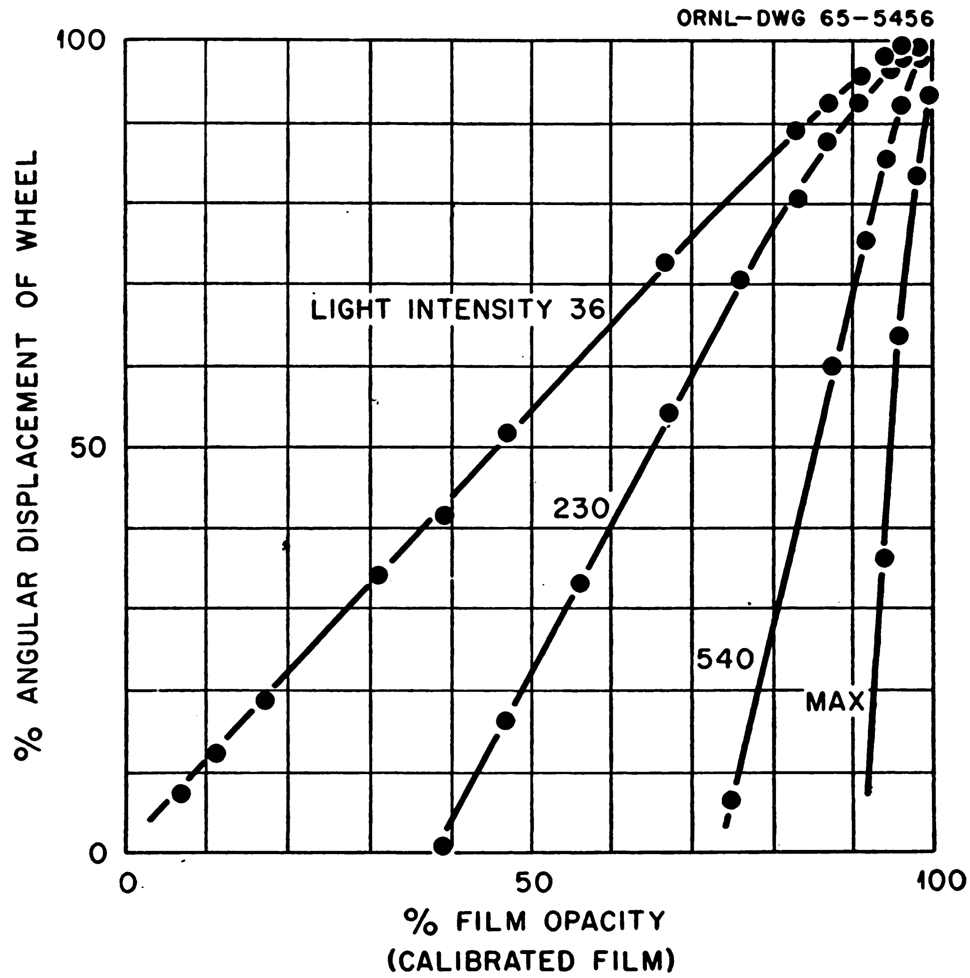

Fig. 2. A plot of angular displacement of the color wheel versus relative film opacity, with several settings of intensity of light from the source behind the original scan record.

A novel "optical potentiometer" was developed to overcome this difficulty. The position information is derived from a light sensor that views a light source through a crescent-shaped gap in the color wheel. Since the opening changes with rotation, the amount of light reaching the light sensor signals wheel position. This system, therefore, provides the error signal needed for the comparator. Since the wheel is out of sight, its position is indicated also by a panel meter.

The rotation range of the color wheel can be made to cover different fractions of the opacity range of the record being scanned as shown in Figure 2. The numbers indicating light intensity correspond to settings of a ten-turn rheostat used to control voltage on the incandescent-lamp source. This corresponds exactly to "background erase" and allows the analysis of the record over a chosen opacity range.

The net result is that each recorded color corresponds to a definite range of film opacity. For example, the range from 0 to 20% of the maximum wheel rotation can be violet, 20 to 50% blue, and so on up to white from 90 to 100%.

THE DEVELOPMENT OF COLOR ARRANGEMENTS

The choice of colors was made with a somewhat schizophrenic approach. At first, there was a tendency to use a natural spectral sequence, as Adams and Jaffe did. This seemed satisfactory at low response, especially when good contrasts between violet, blue and green were provided, since it gave an impression of *coldness*. At the *hot* end of the range, however, the sequence green-yellow-orange-red did not seem to give as satisfactory an impression as the sequence green-red-orange-yellow-white. The latter order is seen to parallel the colors

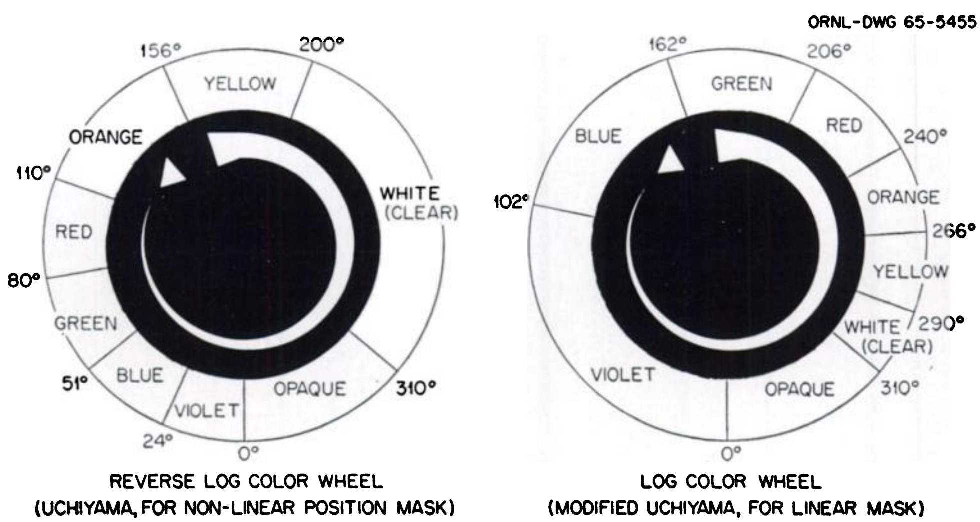

Fig. 3. Layouts of colors used on two of the color wheels, showing also the position-sensor aperture mask. Early masks were slightly nonlinear requiring some adjustment of the width of color segments.

exhibited by heated objects. In addition, it was found that, with Polacolor film, the spectral sequence seemed to give poorer contrast between adjacent colors. The color arrangements shown in Figure 3 illustrate those used in most of the experimental work. (The orange color used does not provide sufficient contrast, especially in copying from the Polacolor prints, and will be omitted.)

The inner portion of the wheels shown in Figure 3 illustrate one type of position-signal mask used. The triangular sections at the ends of the aperture are for braking.

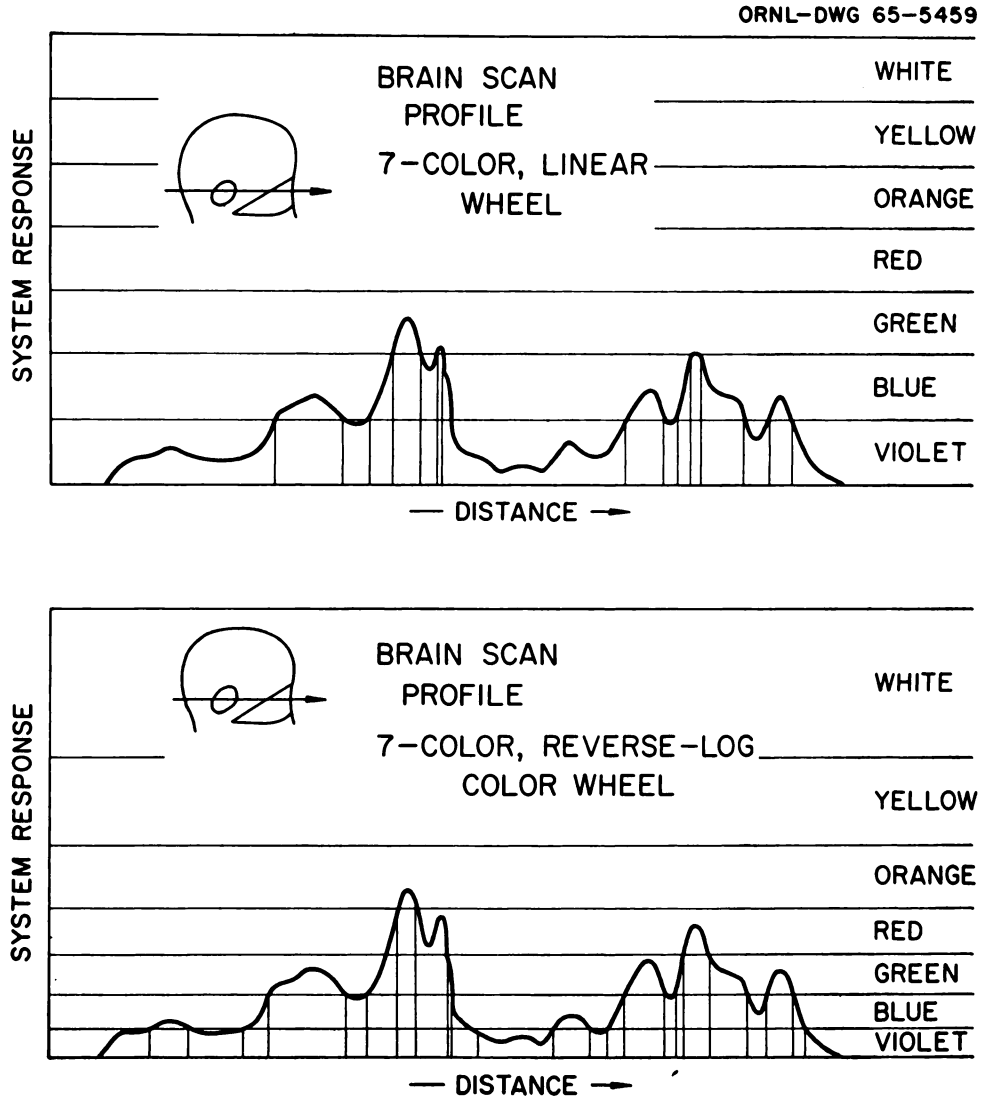

Fig. 4. Plots of system response on single sweeps over a brain scan, superimposed on two color arrangements and showing the expansion provided by the "reverse-log" arrangement.

The scan records used during the initial evaluation of the device had different opacity ranges, depending on the organ or target portrayed. For example, the brain scans used had a low range of opacities. For this reason, a simple linear arrangement of colors did not give results as good as those obtained with special arrangements. Figure 4 shows typical profiles of system response obtained by moving the sensor in a straight line over an original photorecording. With the linear wheel we found that changing the system sensitivity to spread the response over all the colors resulted in a very ragged and unsatisfactory color rescan picture. The "reverse-log" wheel was developed to increase the number of colors used while keeping the system sensitivity at a setting that maintained an acceptable amount of raggedness in the rescan record.

The same approach was applied to the original liver scan photorecordings, and resulted in the seven-color "log" wheel, shown in Figure 5. The choice of

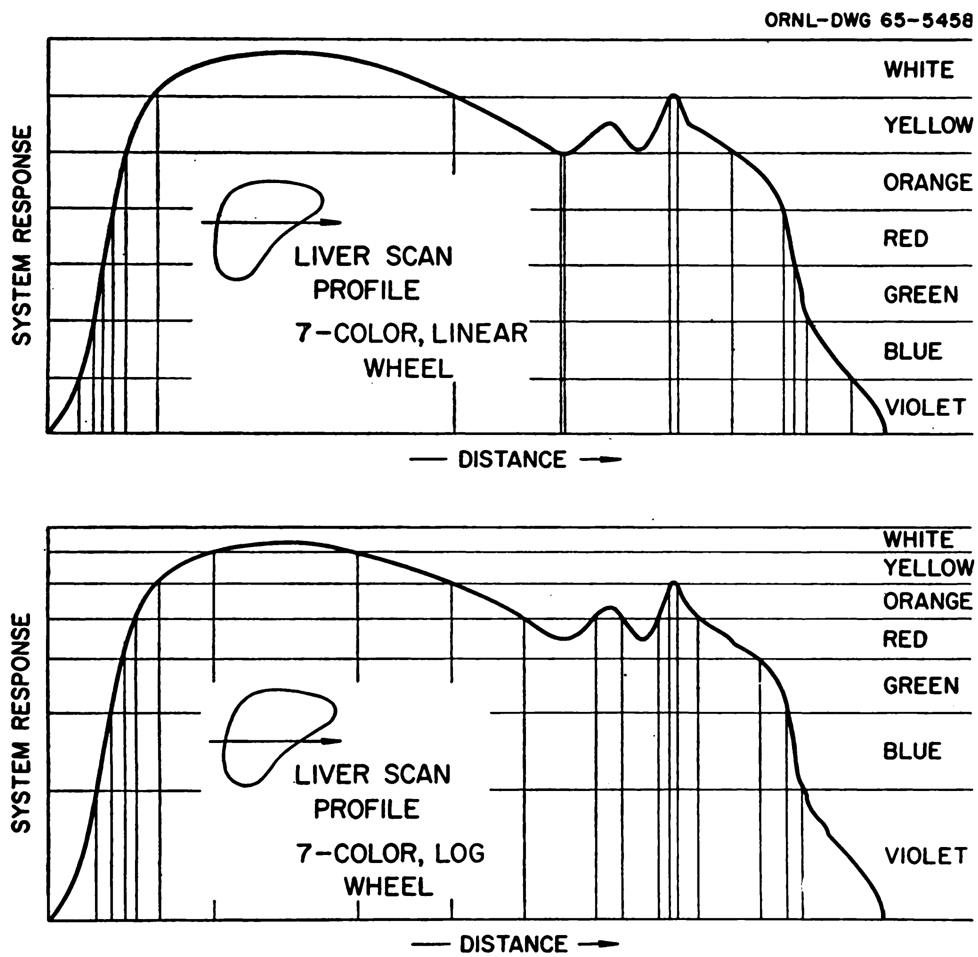

Fig. 5. Plots of system response on single sweeps over a liver scan, superimposed on two-color arrangements, linear and "log."

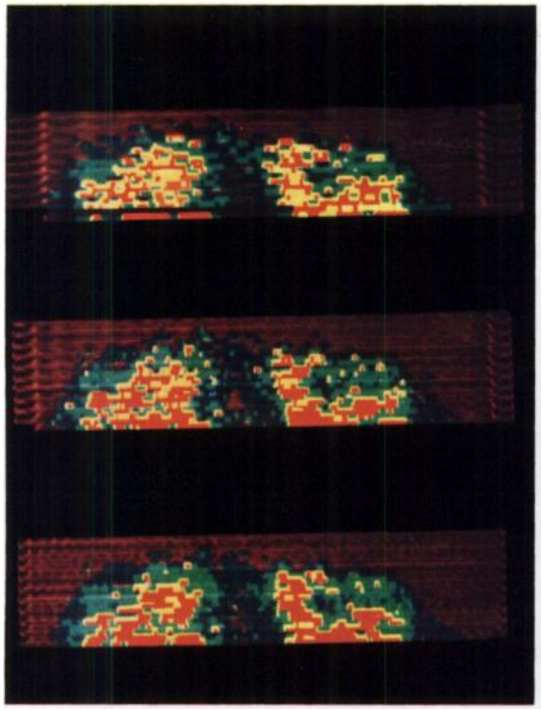
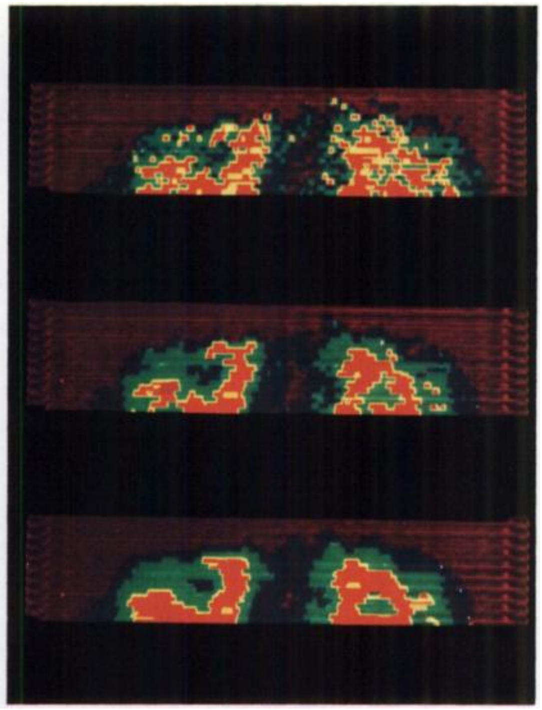
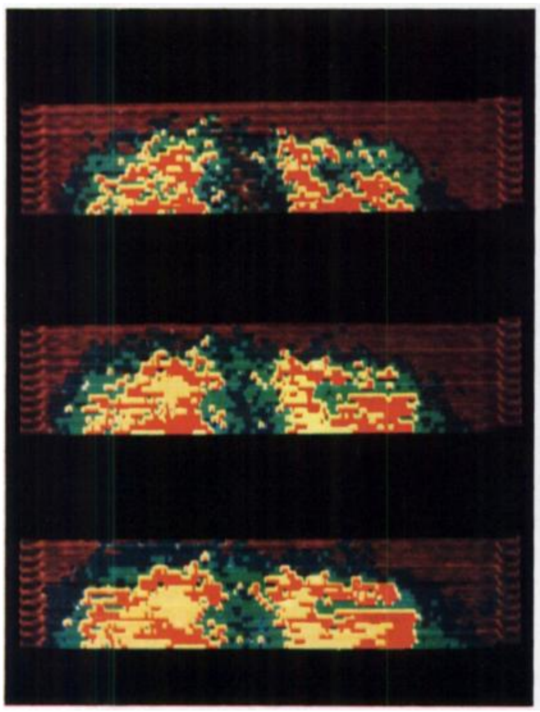
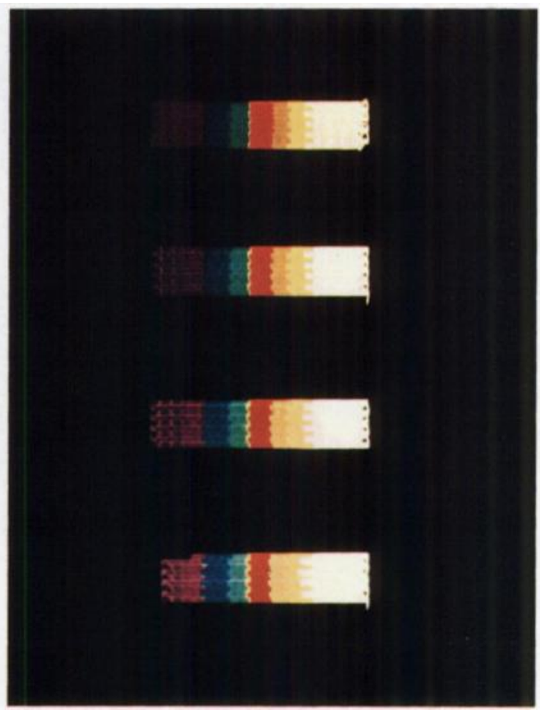

Fig. 6. *Upper Left:* Color rescans of a part of a clinical subject, showing the effect of scan speed. At high speed "scalloping" is evident owing to inadequate rotational speed of the color wheel. Scan speed, decreasing from top example to bottom, 2-, 1-, and ½ inch per second.

Fig. 7. *Upper Right:* Color rescans of a part of a clinical subject showing the effect of sensor aperture. Aperture diameter increasing from top example to bottom, ¼, ⅜, and ½ inch.

Fig. 8. *Lower Left:* Color rescans of part of a patient scan showing the effect of varying the intensity of light for the film sensor. From top example to bottom, threshold set at 0, 20, and 30% of maximum opacity.

Fig. 9. *Lower Right:* Color rescans of test pattern, showing the effect of color film exposure. Exposure increasing from top to bottom examples. Source: tungsten bulb with light blue filter.

colors and their various arrangements are still under experimentation, but the two examples shown, especially with orange removed, seem to be adequate for a large variety of clinical scans.

FACTORS AFFECTING USE AND RESULTS

Since no averaging of the count-rate-meter type is used, there is no intrinsic time lag to cause "scalloping". With the first experimental device, however, a scalloping effect is evident and it is caused by lack of sufficient speed in the servomotor and color wheel combination. Figure 6 shows the effect of scan speed on the appearance of the color record. The original was a section of a clinical scan; it is used here only as a type of test pattern. The top section was done at two inches per second, the middle at one inch per second and the bottom at one-half inch per second. The spacing and sensor aperture were the same for all three; the camera aperture was set, in each test, to give the same effective exposure on the color film. This illustration shows that the device in its present state has insufficient servo speed to give satisfactory results at two inches per second, but is adequate at the other speeds. We expect the servo speed of the next model will be considerably improved.

Naturally, the larger the sensor aperture—or the larger the area of the original record over which the opacity is averaged—the more the rescan record is smeared. The effect of sensor aperture size is shown in Figure 7. The rescan records, from top to botttom, were obtained with aperture diameters of one-fourth inch, three-eighths inch, and one-half inch. The intensity of the light for the record sensor was adjusted as needed to normalize the general appearances of the color records. Some smearing is necessary for good contours.

The "threshold" effects predicted by the data of Figure 2 are shown in Figure 8. The color records, from top to bottom, were made with the threshold set at 30%, 20% and 0%, of maximum opacity.

Obviously, the exposure chosen for the color film itself will have an effect on the appearance of the final record. Figure 9 shows four test patterns made with several aperture settings of the Polacolor camera lens. From top to bottom these are f 4.5, f 4, f 3.5, and f 2.8. The source that illuminated the color segments was a tungsten bulb covered by a light-blue filter.

In the first model of this instrument it was desired to have the system respond linearly to film opacity. This required linear operation of the film sensor, easily achieved by feeding the sensor output into an amplifier with low input impedance (less than 150 ohms). It also required a position-sensor aperture that increased in width linearly with wheel rotation and this was not fully achieved with the crude masks used at firsts. Later aperture masks seem to be truly linear. Logarithmic or other nonlinear characteristics could be provided, though perhaps at the cost of some trouble.

Although the system was designed to rescan the most common form of scan recording, i.e. photorecordings, it can be used to rescan photographic copies of any kind of original. Negative copies may be rescanned by using a color wheel with reversed color sequence and by changing a reference voltage for the panel meter circuit.

DISCUSSION OF PRELIMINARY RESULTS

Results obtained to date with this device indicate to us considerable promise and usefulness. While it is perhaps true that there is nothing in the rescan record that is not in the original record, this device makes scan information more evident. Moreover, since opacity of the original record can be related to counting rate with a calibration wedge, there is a definite quantitative relationship between colors in the rescan picture and counting rate in the original record. This quantitative relations, and the averaging function of the instrument, leads us to believe that a perfected clinical model of this device could be useful. It seems to show special promise in the reprocessing of faint or washed-out photorecording originals that, due to causes such as failing light source or weak developer, are difficult to interpret with the eye alone. A strong advantage is that settings required to use color recording at its best can be determined after the patient is scanned, eliminating guesswork at the time of the patient scan. Examples of rescans obtained with several clinical scans will be shown in a forthcoming paper (4).

A second model is being developed in an effort to correct weaknesses revealed in experimentation with the existing instrument. An additional objective will be the production of a device of minimum cost, reasonable simplicity, and maximum effectiveness.

SUMMARY

Readout limitations in the original rescanner (an analog computer system for scan record analysis) prompted us to explore photographic color recording as a readout. This resulted in a definite quantitative relationship between colors in rescan record and the opacity of an original record, averaged over a definite area. The contour-map nature of the final record seems to be a useful way of presenting re-processed, or "computed", scan information.

Preliminary results are gratifying, and though they indicate the need for a better and faster system, it appears that this method of computer analysis of scan records is promising.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the guidance and criticism of P. R. Bell and D. A. Ross, and the help of Mrs. Ann Miller in manuscript preparation.

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