The Laser Film Digitizer: Density, Contrast, and Resolution

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This work evaluates differences in density linearity, contrast, and resolution of digital images acquired from a laser film scanner. A calibrated photographic step tablet tested linearity of diffuse optical density (OD). It was digitized within center openings of a dark and light film. The 14- × 17-inch films were scanned into 1024 × 1280 picture elements of 8 bits. A photographic tapered resolution guide evaluated the scanner's detail resolution. A single characteristic curve adequately represents the rate of change of OD per pixel value, but two piecewise linear functions are better. One ranges in light OD and a second in dark OD. Contrast shows a steeper slope in a light film rather than a dark film, yet a greater difference exists between two identical digitizers. The resolution test diminishes at 1.3 line pairs per mm (LP/mm), which compares to a Nyquist limit of 1.44 LP/mm. Such density, contrast, and resolution tests yield a benchmark to assure quality operations.

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IT HAS become customary to describe the characteristics of film radiographic systems in their effect upon display contrast, resolution, and optical density (OD). They are complex interacting factors that are well understood in the film domain. Although there have been some recent reports discussing some factors with respect to laser film scanners,¹⁻⁵ none have elaborated fully on these factors' interrelationships. We have deployed two laser film digitizing systems for teleradiology consultations in the radiology department (TELEPRO, Advanced Video Products, now E-Med, Littleton, MA; an OEM version of the LUMISCAN 150, Lumisys Inc, Sunnyvale, CA). We have assembled several test films and designed experiments to quantify the capabilities and limitations of these digitizing systems. The digitized images of the test

films will reveal these intrinsic effects. Once digitized, the video monitor can manipulate contrast and brightness to further influence image factors.^{6,7}

This work may help the radiology department rely upon the new laser digitizing film scanners as a source of digital images. A benchmark, established now for this digital modality, will improve quality for future modalities, for example, Digital Communications in Medicine (DICOM-3). The discrete pixel image representations portray limiting characteristics of the laser film digitizer, analogous to the film's portrayal in a film/screen/viewbox medium. The test films will permit observation of such characteristics. In context, well-known sources of images will better evaluate the system's image quality. Although the test films are not identical to clinical films, they allow evaluation in the context of the original manufacturer's engineering tests.⁸

The digital film's brightness distribution encodes its characteristic relationships: brightness translates into OD, perceptibility translates into contrast, and detail translates into resolution. Optical density, contrast, and resolution tests relate the output ranges of the scanned digital images from given input ranges of film images. These terms are familiar in the radiographic film paradigm. These tests compare two laser scanners used for several years in a picture archiving and communications system (PACS) for teleradiology.⁹ The following work is presented first in schematic as a description of the laser film digitizer. Next through digitization of test films, we identify image characteristics of density, contrast, and resolution. Then their relationship results clarify the imaging factors due to use of the laser film digitizer.

MATERIALS AND METHODS

The laser film scanner digitizes 2048 × 2560 pixels at 12 bits binary value (Fig 1). Because our monochrome monitor limits display buffer size, this study also limits resolutions to 1024 × 1280 pixels and 8-bit depths of gray scale. Several modes are possible, including variable-sized films and compressions. Possible film sizes are 8- × 10-inch, 11- × 14-inch, and 14- × 17-inch. After film scanning, the digital image may be stored uncompressed, lossless compressed, or lossy compressed. We tested the image characteristics with 14- × 17-inch film size and no compression. Through translation by a 12-bit to 8-bit

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Fig 1. Pinch rollers feed a laser film digitizer. Beam reflections off a vibrating mirror sweep each horizontal line. An integrating cylinder collects the pixel's diffuse transmission. An analog to digital (A/D) converted 12-bit value is log amplified from the photodetector, storing only 8 truncated bits.

look-up-table, the scanner retains the eight most significant bits per pixel of those 12 bits digitized. Specifications allow density digitization from 0 OD to 3.5 OD, using a laser spot size of 100 μm .

We test OD with a photographic density step tablet traceable to the National Institute of Standards and Technology (NIST) (part number 07-460, Nuclear Associates, Carle Place, NY). It can assess linearity of optical density with 8-bit digitized values. It displays 21 steps, each differing in transmittance of 0.15 OD over a range from 0.03 to 3.0 OD (Fig 2). The laser film digitizer scans the input step tablet to an output digital image of the film. A region of interest (ROI) average assigns 8-bit pixel values to each density step by covering approximately 40% of its area. They help us decide whether the laser film scanner preserves a linear relationship of value versus density. A linear regression of the ROI average versus density shows the relation of the pixels' luminance to the diffuse density over the 21 test steps.

High contrast of the laser film scanner is demonstrated using the same photographic step tablet. It is placed within a black film surround, on one hand, and compared with one within a clear surround, on the other hand (Fig 2). The difference in radiographic density defines contrast in the image. Using a dark background, the straight line slope (pixel value/steps) provides a reference calibration. The slopes for each background equal the contrast effect.

We think of detail as a function of the intensity of an image

over its spatial coordinates. Detail defines resolution as the limit of brightness variance that can be observed in space. The resolution experiments upon the film scanner use Stouffer 1-T Resolution Guide (Stouffer Graphic Arts Equipment Co, South Bend, IN) (Fig 3). The resolution film has an arc segment of a star test pattern of 10 line pairs. The spokes radiate out a distance of 62 mm from center. The 10 pairs intercept a circumferential segment of length 11 mm. Thus, each line pair intercepts 1 degree of arc. Such a process portrays spatial frequency response.

RESULTS

Because the NIST traceable diffuse transmission density for the 21 test steps is in a straight line, the digital values compare favorably with the true OD. The brightness, that is, the inverse density, within the pixel represents the 8-bit digitized pixel value over an OD range of [0, 2.3] (Fig 4). The test of one scanner over a period of 3 years shows that a single line fits the pixel value when OD is less than 2.3 (Fig 5). It accounts for 99% of the variance. Differences of the linear relationship arise between scanners and over time when the OD is greater than

Fig 2. The photographic step tablet has 21 linear ODs in steps of 0.15 OD, range [.03, 3.04]. A cutout film slot carries the tablet to measure contrast in backgrounds: a dark background at 4.0 OD and a light background at 0.20 OD. The dark steps show a pixel value difference (Δ).

approximately 2.3. Departure from a single line fit is evident in the dark density levels.

The dark densities show a contrast difference (Fig 5). They depart from the linear relationship when OD exceeds the range [0, 2.3] and show an absolute value difference between both backgrounds and steps. They depend upon the surround background of the two different density steps. The two darkest density steps show the largest difference, 16 for the dark and 11 for the light backgrounds (see Fig 2). Between the darkest steps 20 and 21, this equals an OD difference of 0.10, almost 70% of the true step difference of 0.15 OD. One also may consider for the dark areas that the difference in slope is a contrast ratio indicator. The dark background straight line is a reference and the range of density steps is 13 to step 21. The slope becomes 0.15 OD per step for the dark background but 0.14 OD per step for the light background. The maximum/minimum luminance transmitted defines

the contrast ratio. The test film shows them to be 15.5 and 12.9 for the dark background and the light background, respectively. The lowest contrast ratio is seen in this step film at the higher ODs. For a range of [.05, 2.0] OD, a single linear calibration is sufficient despite the background extreme difference. Use of a piecewise curve better represents the background dependency difference over a larger range of OD. So ultimately dark digitized values in a sea of light areas will be different from dark digitized values in a sea of black. In application with a typical radiograph, the detection of so small a difference is not noticeable. The clinical situation usually manifests random background scenery.

The test film of radiating line pairs sorts out two spatial effects, both quantization and resolution (see Fig 3). When digitized, the resolution test pattern appears jagged when coursing diagonally through the digital matrix. The jagged appearance of the line displays the quantization effect. At each

Fig 3. Angled lines cover a 20% area of a test guide. Positive and negative sectors test from [0.82, 67.2] LP/mm. The 10-line pattern, 1.1 degrees/line, interferes with the matrix sample as a Moiré swirl. The resolution limit occurs when 9 lines are distinguished (1.3 LP/mm). (Courtesy of Stouffer Graphic Arts Equipment Company.)

Fig 4. Optical densities are linear over 21 steps of the test film. After scan, a linear regression fits the derived pixel values. The graph shows a straight line association at each step. From the correlation, pixel values can be converted from and converted to ODs by use of side scales.

horizontal increment, one counts the number of ray lines crossing the vertical. The number of starting rays is 10, but when the number reduces to 9, then the sampling is insufficient. This is called aliasing. As one moves closer to the convergence point, that is, at successive higher spatial frequencies, the number of line pairs reduces in succession until none are distinguishable. The plot of number of line pairs observed versus line pairs per millimeter (LP/mm) shows this reduction from 10 to 9 at 1.3 LP/mm (see Fig 3). This limit compares with the digital sampling rate of the laser scanner and expected Nyquist frequency. Because the ray make-up of the test pattern is a continuous range of frequency space and angle, the line pairs converge to the center; and the brightness matrix samples the film as a discontinuous grate.

DISCUSSION

A point densitometer (Model 331, X-Rite, Inc, Grandville, MI) measured the true OD values of the tablet of 21 steps. The point densitometer measures density differently than the laser scanner. The two methods collect light differently as transmitted through each film point after illumination. The point densitometer measures the OD of a single point, like a confocal optical system. Each film point's brightness is a collection of scattered light also, trying to capture the light source's scattered diffusion. The laser light is collected over an angle of 120 degrees (see Fig 1). The departure from straight line correlation with the laser measured densities per step may be due to the design of the

light-integrating cylinder. Light is not collected from the vertical direction, so it does not contribute to the total. Electronic hysteresis partially may explain this effect, too. The rapid transition from light to dark retards stability.

The laser film scanner translates a radiograph into a digital form. Digital image workstations then may display, process, and interpret them. By taking recourse to the digitized image, we have seen that there may result effect upon detail, contrast, and density in comparison to its original film. As long as the radiologists and physicians know the characteristics of this digital imaging system, then they may depend reliably and confidently upon such digital modalities.

CONCLUSION

This work described techniques to test characteristics of laser film scanners using inexpensive commercially available test films. Density, contrast, and resolution are already intuitive to the radiologist. Density may be associated with laser scanned values through the linearity relationship of OD with 21 steps of gray scale. Our sense of reliance upon true optical density is tempered by the contrast dependence upon background. Finally, the resolution technique allows visualization of the pixel formation so different from continuous film imagery. In addition, it shows the digitizer's resolution limits by considering the line pair count versus expected LP/mm. These techniques establish reference standards at the time of installation, but, moreover, we have seen more difference between two scanners at one time than difference between times of one scanner.

Fig 5. Large differences exist at ODs above 2.3. Two scanners differ by 8% at the darkest measured densities. The difference also exceeds 5% in one scanner between 1993 and 1996.

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