INSTRUMENTATION

Evaluation of Computer Display Systems Using Digital Test Patterns

Tom R. Miller, Kondapuram Sampathkumaran, Daniel R. Biello, and Michael W. Vannier

Edward Mallinckrodt Institute of Radiology, Washington University School of Medicine, St. Louis, Missouri

Two digital test patterns are used to evaluate computer video display systems. One pattern consists of linear and logarithmic gray-scale wedges, blocks of constant brightness, and horizontal and vertical bar patterns. The other is a cross-hatch bar pattern. These patterns are used to assess display systems' gray scale, resolution, and spatial linearity. Microdensitometry measurements were performed to determine brightness uniformity, spatial resolution, and to relate optical density to exposure. These test patterns, used qualitatively, are useful in the routine adjustment and quality control of digital systems. The precise quantitative characterization of a display system is important in research applications involving image processing.

J Nucl Med 22: 264–268, 1981

With the increasing use of computers in nuclear medicine, ultrasound, and computed tomography, images are now routinely generated from digital data displayed on video monitors. Well-established methods exist for evaluating the performance of the imaging device (*1*), but little effort has been devoted to testing computers' video display systems. It is self-defeating to improve the quality of image acquisition and then lose much of the advantage in the display. The routine adjustment and quality control of all computer-based imaging systems should include evaluation of the display system. Comparison of different computers should include systematic evaluation of their display capabilities. Research in digital image processing demands quantitative characterization of the entire imaging system, including the display and recording devices.

In this paper two digital test patterns are utilized to evaluate computer video display systems used in nuclear medicine. The essential role played by these test patterns in routine adjustment of the displays is emphasized, and their use in qualitative comparison of different display systems is presented. A series of precision quantitative measurements were performed to illustrate the use of the patterns in characterizing display systems used in applications involving research in image processing.

MATERIALS AND METHODS

Fortran programs were written to generate two digital test patterns. In each case the image size was 256 × 256 pixels, with 256 gray levels. The first test pattern (Fig. 1) is a complex pattern described by Andrews (*2*). Continuous linear wedges, 16 pixels wide, run along the upper and left-hand margins, with pixel values varying from 0 to 255. The right-hand and lower bars are 16-step, 16- by 16-pixel wedges, with pixel values varying logarithmically from 0 to 255. In the center are 16 blocks, each 32 × 32 pixels, with constant, equally spaced values from 0 (lower left) to 255 (upper left). The remaining 48 × 48 pixel blocks are horizontal and vertical bar patterns with alternating 0 and 255 pixel values. Bars vary from 1 to 6 pixels wide.

Figure 2 shows the second pattern, which consists of crossed horizontal and vertical single-pixel bars spaced 16 pixels apart. The bars have value 255 while the background value is 0. A 16-pixel border encloses the cross-hatch.

These test patterns were displayed using three computers in our department. Two are dedicated nuclear

Received Aug. 13, 1980; revision accepted Nov. 6, 1980.

For reprints contact: Tom R. Miller, PhD, MD, 510 S. Kingshighway Blvd., St. Louis, MO 63110.

FIG. 1. Test Pattern 1. Continuous linear wedges extend along upper and left margins, with pixel values varying from 0 to 255. Logarithmic step wedges run along bottom and right side. In center are 16 blocks with equally spaced pixel values between 0 and 255. There are horizontal and vertical bar patterns with bar widths varying from 1 to 6 pixels.

medicine minicomputers: one a microprocessor-based turnkey system and the other a machine employing an LSI-11 microprocessor. The third is a general-purpose minicomputer. The two clinical machines have 64-gray-level monochrome monitors with Polaroid and radiographic film cameras. One of these, used in gated cardiac blood-pool studies, is connected to a video tape-recording system. The general-purpose computer has a video system with 256 gray levels and simultaneous monochrome and color video output to monitors equipped with Polaroid cameras.

For the radiographic film recording, a high-quality, single-emulsion film with wide contrast latitude and good resolution* was used. Polaroid Type 107 black-and-white positive film was used with the Polaroid cameras. In all cases (except for Fig. 4, described below) the monitor and camera settings were adjusted by trial and error to maximize the gray-scale range.

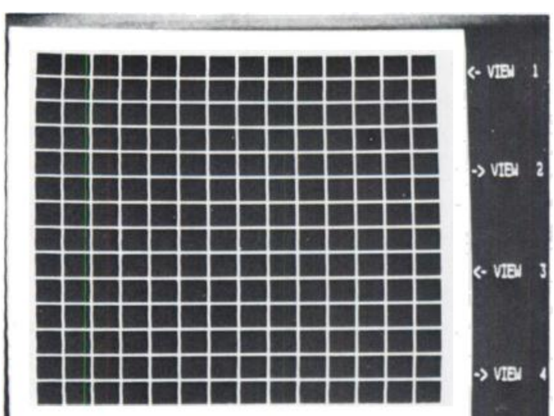

FIG. 2. Test Pattern 2, a cross-hatch pattern, with single-pixel bars spaced 16 pixels apart, and a 16-pixel border.

Adjustment and evaluation of the gray-scale capability and spatial resolution of a display system was readily made with the first test pattern, as described below. The second pattern was used to evaluate and adjust monitor linearity.

For quantitative evaluation, representative radiographic film and Polaroid images were sent to a commercial laboratory† where quantitative microdensitometry measurements were performed. Images were scanned with either 0.1 or 0.05-mm resolution using a square aperture with scan line spacing of, respectively, 0.1 or 0.05 mm. Optical density was determined with precision of ±0.01 optical density (O.D.) units. The digital data were stored on magnetic tape for analysis.

From the photodensitometry measurements of the gray-scale wedge and blocks of constant pixel values in the first test pattern, graphs of pixel value against optical density were constructed. The variation of optical density across the image in regions of constant pixel values were determined. Display resolution was measured using horizontal and vertical bar patterns of varying width and described in terms of the square-wave response function (*3*).

RESULTS

Figure 3 is an enlargement of a region in the right upper quadrant of Fig. 1. This magnified view illustrates the information on spatial resolution that can be obtained qualitatively from this test pattern. The single-pixel vertical bars, which ideally would be displayed as black and white lines of equal thickness, are obviously blurred. Also, the sharpness of the line of transition between the large blocks can be qualitatively assessed. A small hand

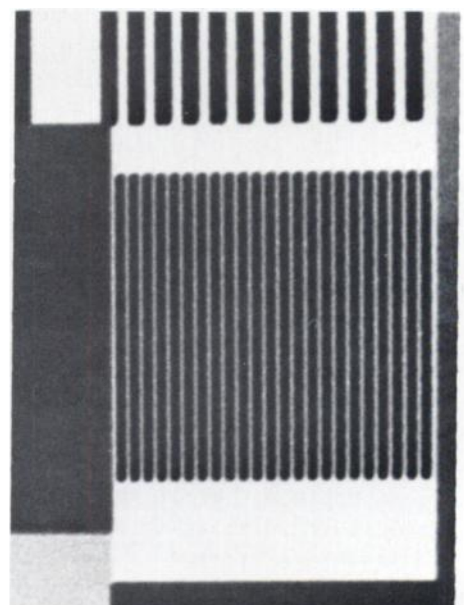

FIG. 3. Enlargement of region in right upper corner of Fig. 1.

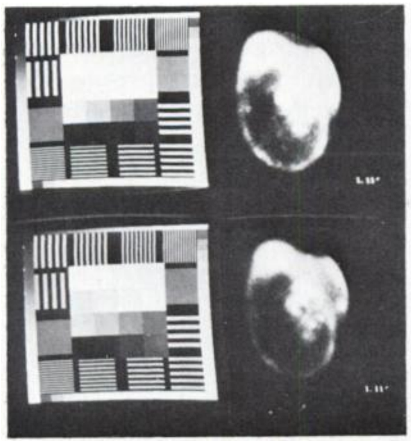

FIG. 4. Upper panel: Test Pattern 1, with brightness and contrast set for pleasing appearance to the eye. A liver scintigram is shown with these settings. Lower panel: test pattern and liver image with monitor set to optimize gray-scale range.

magnifying glass facilitates these determinations with the original images.

The value of Test Pattern 1 in adjusting monitor brightness and contrast is illustrated in Fig. 4. Here the video monitor was adjusted for good gray-scale range when viewed directly. Without readjusting the brightness or contrast, Polaroid photographs were taken of the test pattern and of an abnormal liver scan (upper panel). Then, using Test Pattern 1, the brightness and contrast controls were readjusted for optimum gray-scale range on the Polaroid film. The test pattern and liver image were then photographed again (lower panel). The improved detail with proper monitor adjustment is quite apparent.

In Fig. 5 the cross-hatch pattern is shown displayed on a different computer than that used for Fig. 2. Comparison with Fig. 2 reveals that the video system is not displaying the first 12 rows of the image. Also, display nonlinearity is evident, especially in the right lower quadrant.

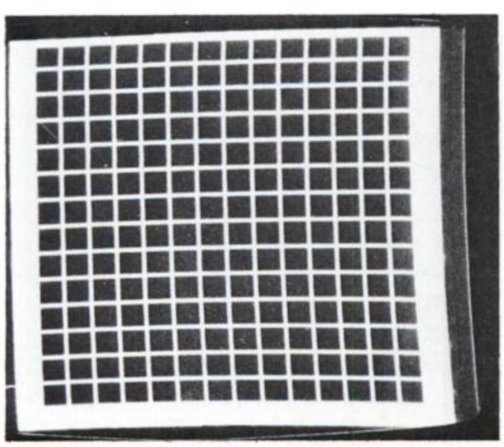

FIG. 5. Test Pattern 2 displayed on different monitor than in Fig. 2. Top 12 rows are lost and distortion is evident in right lower corner.

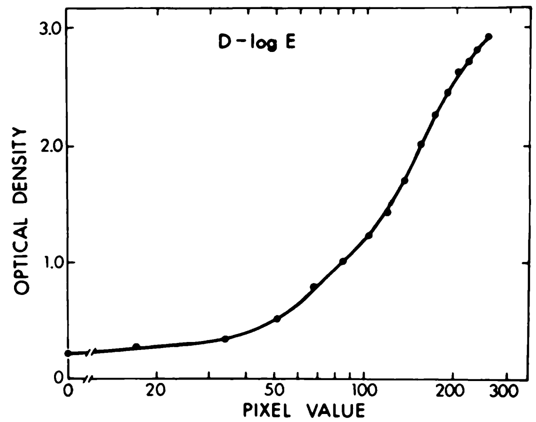

FIG. 6. D-log E curve obtained from image in Fig. 1.

Figure 6 is a graph of optical density obtained from the photodensitometry measurements performed on the test pattern shown in Fig. 1; this is plotted against pixel value on a logarithmic scale. The mean and standard error of the mean (s.e.m.) were calculated for 100 points (1 mm^2) in the center of each of the 16 constant-gray-level blocks. The s.e.m. was less than 1% of the mean value in each block.

Brightness uniformity across the entire field of the image was determined for the 0 (white) and 255 (black) pixel values from measurements of the optical density of white and black regions near the corners of the image and in the appropriate central blocks. For the display system of Fig. 1, the fractional standard deviation (s.d. ÷ mean) for the five regions across the image was 2.4% for the black regions and 14% for the white.

The horizontal and vertical bar patterns were used to quantify the spatial resolution of the display systems. The optical density (O.D.) of scan lines running perpendicular to the horizontal and vertical bars were graphed as illustrated in Fig. 7. The upper panel plots optical density against distance for a line 5 elements (0.5 mm) wide, running horizontally through the center of each of the vertical bar patterns. The ideal response is a step function

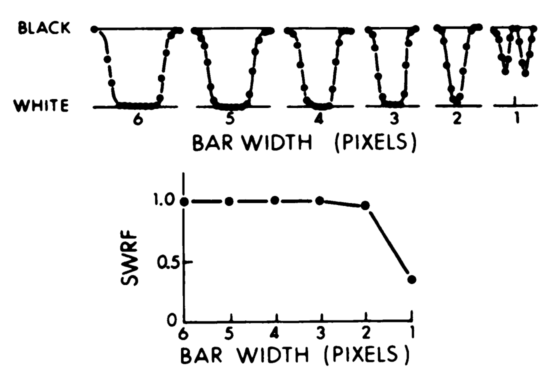

FIG. 7. Upper panel: graph of optical density for vertical bars of Fig. 1. Lower panel: square wave response function for vertical bars of Fig. 1.

alternating between black and white. The square-wave response function (SWRF) (*3*) was calculated for each bar pattern using the formula SWRF = $(O.D._{max} - O.D._{min})/(O.D._{max} + O.D._{min})$. The resulting SWRF for the vertical bars is shown in the lower panel of Fig. 7. Similar results were obtained using the horizontal bars.

DISCUSSION

A computer's video display system consists of a video (refresh) memory, video driver, monitor, and recording system. The video memory contains the digital image. The video driver, which produces an electronic signal based on the numerical information in the refresh memory, drives a raster-scan TV monitor not unlike that in a home television set. The display resolution (frequently 256 × 256 or 512 × 512 pixels) and range of pixel values (e.g., 0–255) is limited by the refresh-memory size. The refresh memory and video driver determine the maximum number of gray levels (16, 64, or 256) that can be generated by the system. The driver circuitry, television monitor, and recording system determine the spatial linearity, resolution, and brightness uniformity of the resulting image.

The digital test patterns presented here permit precise adjustment of the brightness, contrast, linearity, and focus of the video monitor and the settings for camera exposure. Qualitative evaluation of the entire video display system is easily performed and different display systems can readily be compared. For applications to image-processing research, the display systems can be characterized quantitatively.

Qualitative assessment using these test patterns is usually sufficient for display systems used in routine clinical applications. An important role of the test pattern is in adjustment of monitor brightness and contrast controls and settings for camera exposure, using primarily the center 16 squares of Test Pattern 1. This application is vividly illustrated in Fig. 4. It is common practice, when one is photographing a television screen with a Polaroid camera, to adjust the monitor controls for a pleasing appearance to the eye and then to take the picture, usually with adjustment of the camera exposure. This procedure was followed in obtaining the photographs shown in the upper panel of Fig. 4. The high contrast of the Polaroid film results in loss of the upper and lower ends of the gray scale. Without the digital test pattern this error could easily be overlooked, leading to loss of clinical information, as shown in the liver image (top) obtained with the same monitor and camera settings. The test pattern and liver scan obtained with correct monitor and camera adjustment for Polaroid film (lower panel) reveals much greater detail in the liver image. This correct video monitor adjustment gave a very poor, low-contrast image when viewed directly with the eye. This problem is less severe with most transparency films, which generally have a much wider contrast latitude.

Other aspects of display performance readily evaluated are spatial resolution (sharpness), as shown in Fig. 3, and spatial linearity (Fig. 5). Many, but not all, monitors fail to display the top several rows of digital data because of the monitor's retrace blanking. This loss of data was readily discovered with Test Pattern 2 (compare Figs. 2 and 5).

A number of aspects of video display performance may be readily quantitated. The graph in Fig. 6 is similar to the D-log E or Hurter-Driffield (H and D) curve widely used in diagnostic radiology and photography (*4*). The slope of the linear portion of the curve is the combined γ of the film and video monitor, which depends not only upon the film γ, available from the manufacturer, but upon inherent monitor characteristics and adjustment, which can vary widely (*5*). If desirable, this information can be used to modify the gray-level map in the video driver to match the characteristics of a particular combination of video monitor and film. In this way the low and high ends of the brightness range can be expanded to maximize the brightness information available to the eye.

The brightness uniformity, an important parameter of monitor performance, was determined for black and white regions across the entire screen. The small variation (2.4%) among the high-density regions is compatible with published specifications for research-grade video monitors (*6*). The much larger variation (14%) at low light level (0 pixel value) is not surprising, since the system was operating near the level of film fog.

The square-wave response function (Fig. 7) is used with bar phantoms to measure performance of diagnostic radiograph systems (*3*). This function is closely related (*7*) to the modulation transfer function (MTF) used to characterize the resolution of imaging equipment in nuclear medicine, ultrasound, and computerized tomography (*1*). Indeed, as the spatial frequency rises and the SWRF falls, the SWRF and MTF converge toward the same value (*7*). The spatial resolution of a computer's video system can be meaningfully described in this way, as shown in Fig. 7, and different display systems can be quantitatively compared.

These test patterns may be of greatest value when used for routine quality control and adjustment. Both test patterns should be displayed and photographed on all video systems at regular intervals, with frequency determined by equipment stability. We found the greatest image variability in our videotape system, a critically important element in the analysis of gated cardiac blood-pool studies at many institutions.

When display system misalignment is found, adjustment must be made manually by trained service personnel—except, of course, for simple camera exposure and video-monitor brightness and contrast.

Test Pattern 1 is somewhat complex for use simply in routine gray-scale adjustment, where we found the central 16 squares to be of greatest value. However, the additional information contained in this pattern, particularly the resolution bars, makes its routine use desirable as a check of system focus.

Most users of these test patterns will not need to perform the precise quantitative measurements described here. However, for research applications heavily dependent on image quality, such as digital image processing, this quantitative characterization of the display system should be carried out.

FOOTNOTES

* Kodak GTA-1

† Perkin-Elmer, South Pasadena, CA.

ACKNOWLEDGMENTS

We thank Norman A. Page of the Perkin-Elmer Company for performing the microdensitometry measurements. We are grateful to Lorraine DiPlacido for her assistance in the preparation of the manuscript.

This study was supported in part by a Specialized Center of Research (SCOR) in Ischemic Heart Disease HL17646 from the National Institutes of Health.

REFERENCES

1. ROLLO FD, Ed: *Nuclear Medicine Physics, Instrumentation, and Agents.* St. Louis, C. V. Mosby Co., 1977, pp 436–452
2. ANDREWS HC: Quantitative evaluation of software copy displays. *Digital Design* 55–58, 1979
3. LUBBERTS G: Some aspects of the square wave response function of radiographic screen-film systems. *Am J Roentgenol* 106:650–654, 1969
4. HENDEE WR: *Medical Radiation Physics,* 2nd Ed. Chicago, Year Book Medical Publishers, 1979, pp 295–296
5. FREI W: *Photographic Recording of Digital Television Displays,* Application Note, Comtal Corp., Pasadena, CA
6. Product Catalog, Hewlett Packard, Palo Alto, CA, 1980
7. COLTMAN JW: Specification of imaging properties by response to sine wave input. *J Opt Soc Am* 44:468–471, 1954