Proc. SCAR 90 Computer Applications To Assist Radiology, pub. by Symposia foundation Calsbad Ca. 1990

Perceptual and Physical Concerns When Displaying Images to Be Used in PAC/IMAC Investigations

George W. Seeley, Jannick Rolland, Jose Guillen, et al
Department of Radiology and Optical Sciences Center,
University of Arizona, Tucson, AZ

ABSTRACT

Future PAC/IMAC systems will be acquiring, transmitting, storing, and displaying a variety of digital images. Film images will also be digitized and incorporated onto the system. The process of displaying digital images is one of the most crucial parts of such systems. These digital images will be displayed either on film or electronically. Much research is now being done to define the needs of these display systems. One of the ways researchers investigate the needs of PAC/IMAC display systems is to acquire a set of clinical images and digitize them. The resultant digital images are then manipulated in some way and then either written back to film or displayed on an electronic monitor. Reading performance for the original set and the duplicates are then compared using the receiver operating characteristic (ROC) experimental paradigm. For the results of these experiments to be interpreted properly the displaying of the digital image must be controlled such that they are matched as closely as possible to the original film images except for the variable(s) under study. This paper will describe some of the work being conducted at the University of Arizona Radiology Department for controlling CRTs and laser writers to conduct these type studies.

INTRODUCTION

A large amount of psychophysical/clinical research is now being conducted to investigate the needs of PAC/IMAC systems [1-4]. The questions being investigated have become more and more subtle over time as we learn more about what is needed. Thus, the need to control the experimental environment becomes even more pertinent. One of the ways researchers investigate the needs of PAC/IMAC display systems is to acquire a set of clinical images and digitize them. The resultant digital images are then manipulated in some way and then either written back to film or displayed on an electronic monitor. The original set and the duplicates are then compared using ROC analysis. For the results of these experiments to be interpreted properly the displaying of the digital image must be controlled such that they are matched as closely as possible to the original film images except for the variable under investigation.

For example, if an experimenter wants to define whether the spatial resolution of a CRT display is sufficient for making diagnosis of a particular exam type, then the experimenter must make sure that the image on the CRT display matches the original in every way except for the spatial resolution. If the other characteristics of the CRT are not controlled for, then the results of that study do not reflect only spatial resolution differences, but also all the other uncontrolled variables in the system. Thus, no specific conclusions about spatial resolution can be made. This paper (1) describes some of the techniques that we have developed to control CRT displays and laser writers and (2) presents results from studies that show the deleterious effects on perception when display characteristics are not controlled.

DISPLAY TYPES

CRT Displays

When a digital image is displayed on a CRT there is usually not a one to one mapping of the digital values in memory to that which is seen by the observer at the surface of the screen. The CRT and the driver board combine to distort the values actually written to the screen. These two devices and the other electronics in the system contribute to the system greylevel/brightness transfer curve. Depending on the amount of change brought about by this transfer curve this distortion can have drastic effects on detection. A way to account for this is to characterize the transfer curve of the CRT system to be used in the research and then control its output using that information.

We have developed a simple procedure for characterizing the greylevel/brightness transfer curve of a CRT system. First an SMPTE test pattern is written to the screen and the contrast brightness controls are manipulated until the 5% and the 95% difference squares are clearly visible. The brightness and contrast controls are then locked in place and a series of greylevels are written to the CRT screen and the light output is then measured in foot lamberts for each of the steps displayed. We use a simple silicon detector attached to a voltmeter with a digital display to take these measures. We attach the detector to the center of the screen, cover the screen to eliminate scatter due to ambient light and then take the measurements. We have used more elaborate controls and equipment to take these measures [5,6,7], but for characterizing the transfer curve of a CRT display system, we have found this simple technique worked as well as the other.

Figures 1 and 2 are the transfer curves of two different display systems. The same CRT was used in both cases. The only difference was the driver board we used. One was hooked to our VAX 8600 system. The other was in a PC based system. While both have non linear shapes, they are different. Putting the same information into the two systems results in different brightness outputs. We found that these differences have a significant effect on an observers detection capabilities. Figure 3 describes the results of a study we ran to investigate the effect of transfer curves on detection. We displayed the same set of images on the two different display systems characterized in Figures 1 and 2. The images had a noisy background and the signal, when it was present, was always in the center. There were five levels of signal. The images were shown to 6 observers one at time, in random order, and in a controlled experimental environment. The ROC experimental paradigm was used and the observer's task was to tell us their certainty that a signal was present or not. The two curves in Figure 3 are the results of this study. As expected, in both cases as signal increases so does detection. However, the detection of the PC based CRT system is lower than that on the VAX. Efficiencies were calculated [(dH/dI)**2)] comparing the human (dH) to an ideal observer (dI) and as can be seen the PC based system is 35% [(10-6.5)/10*100] lower than that of the VAX.

Once you have determined the shape of the transfer curve it is a simple matter to make a look-up-table (LUT) to change the curve to any desired form. We photometrically linearized our displays and then ran a second study using the PC system to investigate the effect of linearization on detection. The same images and the same observers used in the previous study were used. The task and the experimental environment were the same. With photometric linearization there was a further decrease of 76.9% [(6.5-1.5)/6.5*100] in efficiency from the results of the previous PC study. This decrease in detection capabilities can be explained by the following: when these monitors were linearized, there was a reduction in slope of the transfer curve in the greylevel region in which the signal to be detected, resided. Thus, signal decreased for the observers.

It should be noted that although the transfer curves depicted in Figures 1 and 2 are commonly encountered in a large range of CRT displays, other transfer curves are possible and they might lead to different effects. For example, if linearization has the effect of increasing the slope of the transfer curve in the range of greylevels in which the signal resided, then detection would most likely be increased. However for the range of displays that our transfer curves represent, photometric linearization is obviously not a good candidate for a general display transfer curve.

These studies show how easy it is to affect the perception of observers and to distort they type of conclusions that are drawn from research using CRT displays. Next, we will discuss controlling laser written film to equate optical densities in the duplicate film to the original.

Laser Written Film Displayed on Light Boxes

An alternate way of displaying digitized images is to write them back to film and then display them using a light box. For example, suppose you wanted to investigate the effect of reduced spatial resolution on diagnosis. Affordable and available CRTs cannot display image matrix sizes much over 2000 X 2000 pixels with, at least, 8 bits of grey. This means that images having larger matrix sizes would have to either be displayed piecemeal or displayed by using a reduced matrix size. Neither method is very acceptable for this type of research, thus writing back to film is a popular method for investigations into spatial resolution needs. After the images have been digitized and the appropriate manipulations made to reduce resolution, but before writing them back to film, a crucial step must be taken. A LUT must be devised that will maintain the same optical densities in the duplicate images as those found in the original films. If this step is not taken before generating the images, then the results of such a study will be confounded due to this lack of experimental control.

To avoid this problem we have developed a procedure to insure that the optical densities of duplicate images will be virtually identical to those of the original. When we digitize the films to be used in our studies, we also digitize the National Bureau of Standards (NBS) x-ray step tablet. This tablet has 17 steps of optical density ranging from 0.20 to 4.15. For this work we only use the first 14. The 14th step has an optical density of 2.89. Next we use a computer program to find the average greylevel for each step in the digitized NBS tablet. We then calibrate our Kodak laser writer and film processor to stabilize the output and write out the digitized NBS step tablet. We also write out a digital step tablet that we create in the computer with a greylevel range dependent on the number of bits there are per pixel. For example, if the number of bits is 12, then we create one that ranges from 0 to 4095 in steps of 32. We then process the two images and measure their optical densities. Having the digital and optical density values for both step tablets allows us to make a LUT that, when down loaded into the Kodak laser writer, adjusts the laser's output to equate the optical densities of the laser written NBS step tablet to those of the original.

We did the above process for a set of images we are using in a spatial resolution study. Figure 4 shows the closest we can come to the original NBS step tablet using just the controls built into the Kodak writer. There is some correspondence up to around 2.20 optical densities, but after that point the two diverge significantly. Figure 5 shows measurements of the laser written NBS step tablet with the same control settings as the previous one, but now with our LUT also incorporated into the system. There is virtually identical correspondence for all 14 steps. The last one is only off by 0.01 optical densities. Using the LUT we then wrote the images to be used in the resolution study. Figure 6 shows how closely the images we wrote using the LUT match the original. Sixteen locations were measured for one original image and the same 16 locations were also measured in two duplicate images. One duplicate was written with and one was written without the LUT. As can be seen, the two curves are very similar to those we found using the NBS step tablet. Thus, we feel that we have produced images that vary only in terms of their spatial resolution and the results from our study will reflect only the manipulation of that parameter. As figure 6 demonstrates, without the LUT this would not have been true.

DISCUSSION

In the PAC/IMAC field researchers are asking subtler and subtler questions about system needs. Thus, the need for controlling all aspects of the experimental environment becomes even more important than in the past. We hope to have demonstrated in this paper, (1) that small differences in display characteristics can have large effects on perception, (2) that control of all aspects of the display system is necessary for valid results, and (3) that this control is also possible. Without characterization and control of the kind described in this paper, experimental results and conclusions will have very limited generalizability and usefulness.

Acknowledgements: This work was supported by NIH Grant Numbers P01, CA23417 and R01 CA49261.

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FIGURES

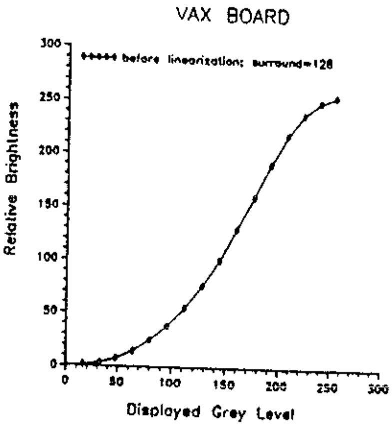

Figure 1. Transfer curve for display board in VAX 8600

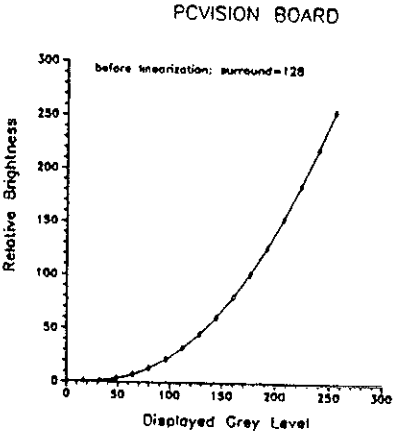

Figure 2. Transfer curve for display board in PC.

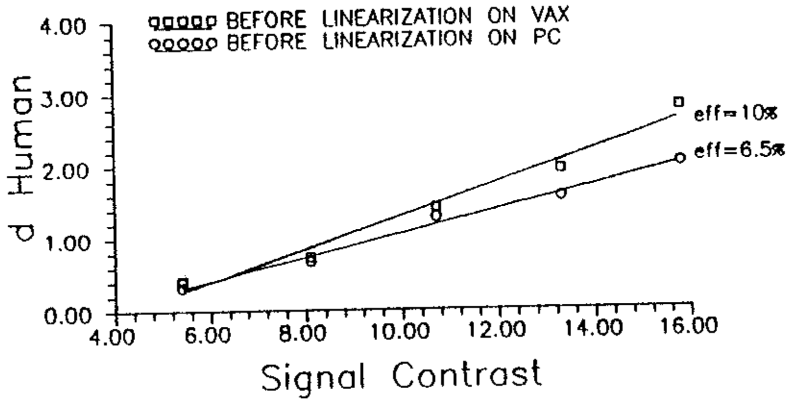

Figure 3. Results from transfer curve psychophysical experiments

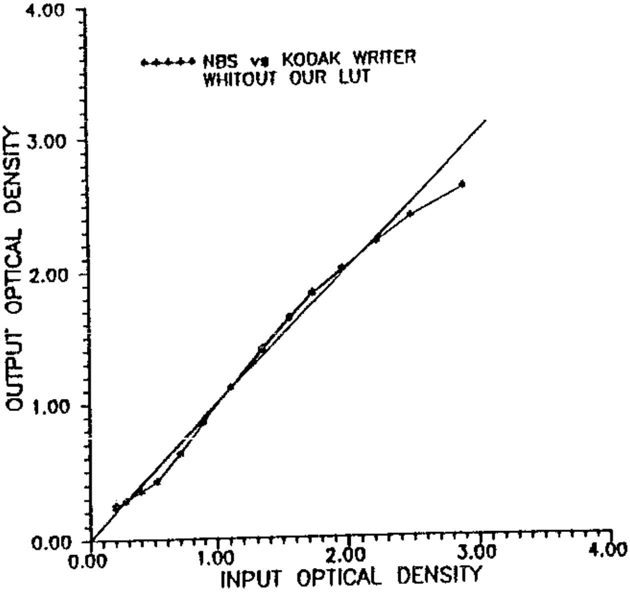

Figure 4. Laser writer output of digitized NBS tablet without LUT

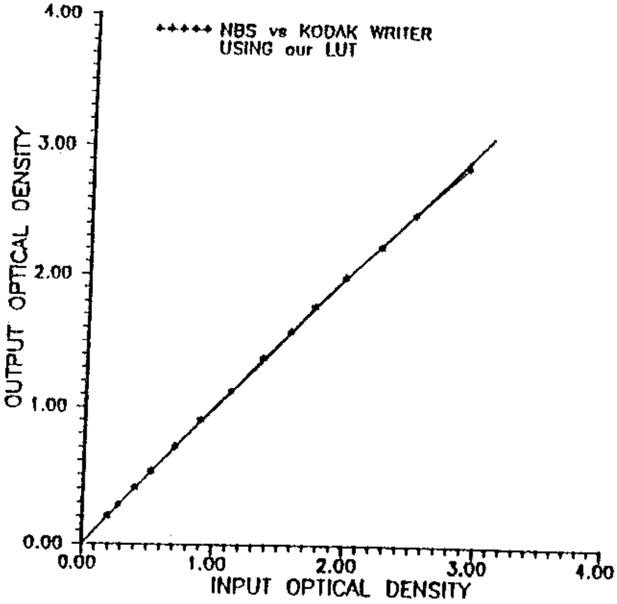

Figure 5. Laser writer output of digitized NBS tablet with LUT

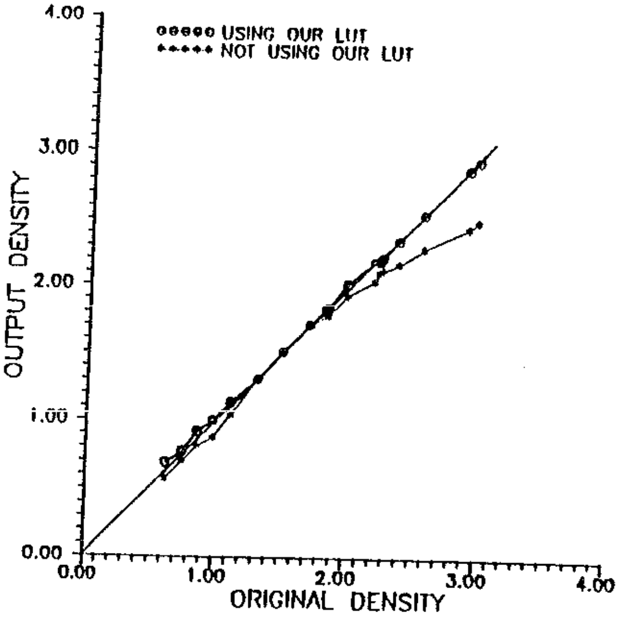

Figure 6. Sixteen measurements taken from an original image and compared to those taken from laser film images written with and without the LUT.