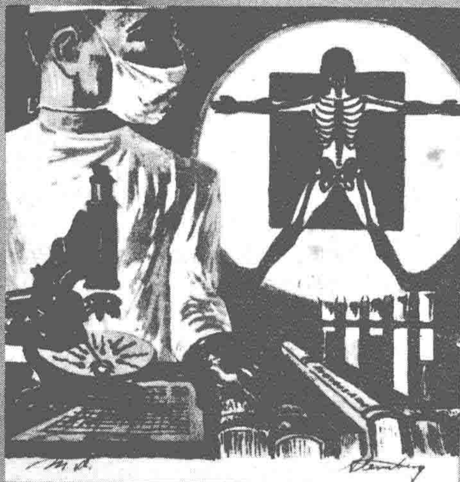
PROCEEDINGS

ISMII '84

International Symposium on Medical Images and Icons

July 24-27, 1984



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ISMII '84

IEEE COMPUTER SOCIETY
INTERNATIONAL SYMPOSIUM ON MEDICAL IMAGES AND ICONS

Hyatt Regency, Arlington, Virginia
July 24–27, 1984

FEATURING: Med**PACS:** Picture Archiving and Communication Systems
Med**PICS:** Picture Interpretation Computers and Systems
Med**GRAPH:** Computer Graphics

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Sponsored by

IEEE Computer Society
Technical Committee on Computational Medicine

1884 1984 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

ISBN 0-8186-0544-9
IEEE CATALOG NO. 84CH2047-9
LIBRARY OF CONGRESS NO. 84-80907
COMPUTER SOCIETY ORDER NO. 544

THE COMPUTER SOCIETY PRESS

Published by IEEE Computer Society Press
1109 Spring Street
Suite 300
Silver Spring, MD 20910

ISBN 0-8186-0544-8 (paper)
ISBN 0-8186-4544-X (microfiche)
ISBN 0-8186-8544-1 (casebound)
IEEE Catalog No. 84CH2047-9
Library of Congress No. 84-80907
IEEE Computer Society Order No. 544

Order from: IEEE Computer Society
Post Office Box 80452
Worldway Postal Center
Los Angeles, CA 90080

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Piscataway, NJ 08854

1884-1984 A CENTURY OF ELECTRICAL PROGRESS THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

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*Not received in time for publication.

PART 1
MedPACS

Session 1A
Display Stations for MedPACS—1

A LINEAR SYSTEMS APPROACH TO MEDICAL IMAGE CAPTURE AND DISPLAY

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ABSTRACT

A picture archival and communications system has been under development at the Hospital of the University of Pennsylvania for the past two years. This system features a fiber optic network, high resolution display for initial interpretation, and a lower resolution display for review and comparison. A laser optical disk will be used for mass storage. A high resolution digital camera is used to acquire images from x-ray film.

This manuscript addresses an analysis of the image resolution, intensity transformations, and noise associated with the digital scanning camera and the high resolution cathode ray tube displays. A linear systems approach is utilized for this analysis.

INTRODUCTION

The picture archival and communication system (PACS) for medical images under development at the Hospital of the University of Pennsylvania has been described previously (Arenson 1982a,b) Digital imaging systems allow the direct acquisition of images already in digital form. However, approximately 80% of the images in the Department of Radiology are still captured on x-ray film. These images are converted into digital form by an Eikonix high-resolution digital scanning camera. We operate this digital camera in a matrix of 1024 x 1024 pixels to match the storage requirements of our imaging network. Twelve bits of intensity levels are recorded.

These image acquisition systems transfer digital images over the fiber optic network to the storage and/or image display systems. The token- passing contention-handling ring architecture of our fiber optic network has been described previously as well (Arenson, 1983a).

There are two types of display systems on the network. Our high resolution, 1024 x 1024 pixel matrix, RAMtek displays are located in the main radiology interpretation area. The other, lower resolution, 512 x 512 pixel, displays for review and comparison purposes, are based on a Gould-DeAnza image array processor and associated image memory planes and video channels. These lower resolution displays will be relocated to our Medical Intensive Care Unit (MICU) for a clinical trial starting this Fall.

The laser optical disk from Philips Medical Systems, Inc. (PMSI) is expected to fulfill the storage needs for our clinical trial in the MICU. The most recent images will also be available on Winchester disks associated with the DeAnza system.

As we have implemented portions of our PACS, many problems have been encountered. Implementation of the ISO OSI network protocol has been difficult and performance has not matched expectations. Our ten megabytes per second fiber optic network is adequate to handle the traffic, but the computer buses limit effective transmission to one-two megabytes per second.

The Eikonix camera is sensitive to fine adjustments and the distance from the lens to the film source cannot be altered without recalibration. Furthermore, we encountered difficulties choosing the appropriate adjustments based on image observation alone.

Therefore, we decided to perform a more rigorous analysis of the effects of both digitizing camera and display systems on the image resolution, intensity transformation, and noise. The following discussion deals with this linear systems analysis approach applied to our PACS.

METHODS OF PROCEDURE

Our PACS (Arenson 1983b) includes components for digitization, storage, transmission, and display of images once films are initially exposed and processed. From a systems viewpoint, the radiologist using the PACS to retrieve and review images obtains anatomic information which has been processed through several different steps. These include: (1) projecting a shadow of anatomic structures onto the film, exposing the film; (2) developing the film; (3) digitizing the image; (4)

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transmitting the digital image from the capture point to the image archive and from the image archive to the image display station; (5) generating a video display from the stored digital image; (6) looking at the video display in the presence of interfering room light; (7) processing these received signals in the radiologist's visual pathways and brain. For this study, measurements were made to characterize digitization (transfer of information from the film to the stored digital image) and to evaluate the high-resolution video monitors.

The linearity of the digitizing camera, an Eikonixscan Model 78/99 Image Digitizer, manufactured by Eikonix Corporation, Bedford, Massachusetts, was assessed. To make the measurements, a standard film stepwedge was first produced. A Tobias Model TBX densitometer was used to measure the diffuse optical density within each stripe of uniform densities on the film. A digital image was produced by scanning the film with the camera. This digital image was then sampled to obtain a mean and standard deviation pixel intensity for each optical density. Figure 1 shows a plot of pixel intensity as a function of the logarithm of film density. With respect to the log density, the pixel intensity is linear over the density range 0.2 to 1.0, but becomes nonlinear in the domain of high optical densities.

To assess the camera's spatial bandpass properties its modulation transfer function (MTF) was estimated. To provide an input signal containing high spatial frequencies to the camera, a film knife-edge or sharp step was fabricated. A flat, rectangular piece of 0.003-inch thick bronze shimstock was used to shield part of a single-emulsion sheet of x-ray film which was exposed using a screenless technique. X-ray beam parameters were chosen in order to provide an adequately large density step on the processed film that was in the linear range of the input-output transfer characteristic (Figure 1). The measured diffuse densities on each side of the boundary were 0.7 and 1.0. This film was used as the test input to the digitizing camera.

Using the digitizing camera, a digital image of the test film was made. A line scan centered about the step transition was abstracted from this image. The window chosen consisted of 32 points; these data were multiplied by a cosine (Hanning) window function. The digital Fourier transform was computed, and the amplitude spectrum was smoothed using a three-point rolling window. To determine the input amplitude at each spectral frequency, a microdensitometer was used to scan the film knife-edge. For this scan, measurements were made every 37.5 microns using an aperture of 40 microns. The digital Fourier transform of these data was computed as an estimate of the frequency spectrum of the camera input signal. Figure 2 shows the microdensitometer power spectrum up to the Nyquist frequency of the microdensitometer.

Since the frequencies in the two discrete Fourier transforms did not correspond, the microdensitometer spectrum was interpolated to provide an estimate of the input amplitude at the image digitizer fundamental frequency and at each of the image digitizer harmonics. The interpolated power spectrum, derived from the microdensitometer data but restricted to the frequency range appropriate to the image digitizer, is shown in Figure 3. The linear amplitude spectrum corresponding to the logarithmic power spectrum of Figure 3 is the set of assumed input values leading to MTF. The output spectrum, the result of digital Fourier transform performed using image digitizer data, is shown in Figure 4, again as a display of logarithm of power. The corresponding linear amplitude spectrum was used as the set of output amplitudes for making the estimate of the MTF.

The modulation transfer function was estimated by taking, for successive frequencies, the ratio of the output amplitude to the input amplitude. Figure 5 is a graph of this estimated MTF.

One of the important characteristics influencing the quality of the digitized image is the dependence of the monitor screen's luminance on the value of the intensity transformation table (ITT). This relationship was measured for three different monitors.

The ITT values were varied through the range 0 to 255 in steps of 8. The data were acquired for the 33 different cases of pixel value in the intensity table. A Tektronix digital photometer (Model J16) was used to measure the luminance of each successive value in ITT. The photoelectric sensor was placed in the center of the monitor screen. The sensor was fixed throughout the experiment on each monitor. The luminance was measured in foot-lamberts (1 foot-lambert = 3.43 cd/m^2). The experiments was carried out 5 times for each of the three displays. The mean value of luminance was used as the basis of the analysis.

The table contains the luminance value of every monitor for the minimum and maximum values of the intensity table.

PIXEL VALUE	LUMINANCE (FOOT-LAMBERTS) MONITOR #1	MONITOR #2	MONITOR #3
0	0.7	0.2	0.6
255	27.4	21.5	23.1

The graph of functional dependence of lookup table value vs. averaged luminance in shown for all three monitors in Figure 6. The nonlinearity in this relationship is evident.

CONCLUSIONS

The graph displayed in Figure 1, showing pixel data output by the digitizing camera as a function of the logarithm of film density, shows good linearity of output response in the optical density range 0.2 to 1.0. The bars on this graph represent mean plus and minus one standard deviation, and the superimposed line represents the regression line giving least square error taking into account the standard deviations of the data points.

The error bars in Figure 1, representing the standard deviation of pixel intensity over the measured regions, permit inferences on the noise contributed by the film and image digitizer to the image. The contrast between a radiographic feature and its background is expressed as

$$C = \frac{dI}{\langle I \rangle},$$

where $\langle I \rangle$ is the average background intensity and dI is the difference between the average feature intensity and $\langle I \rangle$. Feature visualization, however, is limited by the signal-to-noise ratio, defined as

$$SNR = \frac{dI}{s_I} = \frac{C\langle I \rangle}{s_I}$$

where s_I is the root-mean-square (rms) intensity fluctuation about the background intensity $\langle I \rangle$ (Macovski 1983). When the data are digital images captured from film, both the film and the digitizer contribute to s_I.

To assess the rms noise attributable to both of these system components at various film background densities, the standard deviation about the mean pixel value was calculated for each uniform density region of a film stepwedge. These standard deviations are represented in Figure 1 by the error bars. The standard deviations, computed for 100 points in each intensity region, range from 8 to 70 with no trend to have a smaller standard deviation at lower pixel intensity. Other methods of noise analysis of radiographic systems (Arnold 1984, Burgess 1983, Hecker 1982, Ishida 1984) may serve to clarify the affect of system noise on feature detection.

The most significant lessons to be derived from the transfer function analysis relate to the difficulty in performing such measurements on an imaging device and the need to develop better methods which will be less prone to the pitfalls of sampling and computation artifacts. The function displayed in Figure 5 suggests a sharp falloff in frequency response at very low spatial frequencies, near 1 cycle per centimeter. At higher frequencies, the response function shows a large local maximum, but tends to zero only very slowly and is apparently nonzero well past the Nyquist frequency where this graph ends. However, as Figure 2 shows, the spectrum of the film used as input to the system is rich in high frequency components which exceed the system Nyquist frequency and, therefore, may be aliased into the measured frequency range. The high-frequency peak in Figure 4 strongly suggests that this aliasing compromised the validity of the analysis, and additional experiments using more band-limited signals are necessary to improve on the MTF estimation. Additional efforts to assess the frequency response of the image digitizer will be directed at avoiding these pitfalls, and other methods (Metz 1979, Rossman 1971, Sones 1984, Ziskin 1971) will be explored.

The graph displayed in Figure 6 demonstrates for the display monitors that screen brightness is a nonlinear function of the pixel value stored in refresh memory. It is, furthermore, nonlinear and concave upward over the entire range of pixel values. Since Figure 1 shows that the image digitizer responds to the logarithm of film density in a linear fashion, and since it is the log density which represents perceived brightness when radiographic films are viewed on light boxes, it follows that display of images using linear transformation tables will not yield video displays which look like films on viewboxes. To achieve that goal, a transformation function which is concave downward, such as the logarithm function, must be used to condition the image for monitors which respond as shown in Figure 6.

ACKNOWLEDGEMENT

The authors thank Dr. John Haselgrove for his help in obtaining the microdensitometer data.

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FIGURE 1: DIGITAL OUTPUT VS. FILM DENSITY

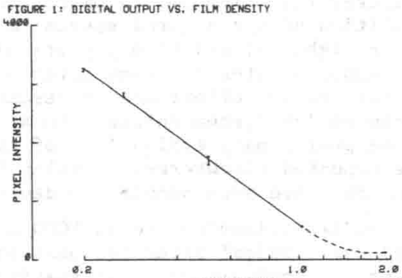


FIGURE 2: LOG POWER (MICRODENSITOMETER DATA)

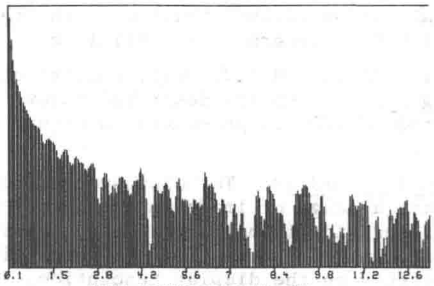


FIGURE 3: LOG POWER (INTERPOLATED MICRODENSITOMETER SPECTRUM)

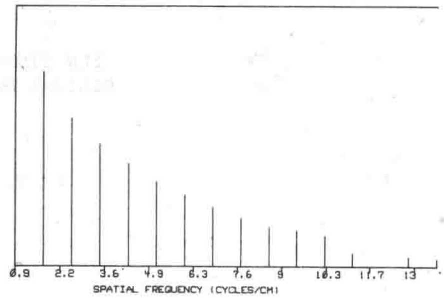


FIGURE 4: LOG POWER (IMAGE DIGITIZER DATA)

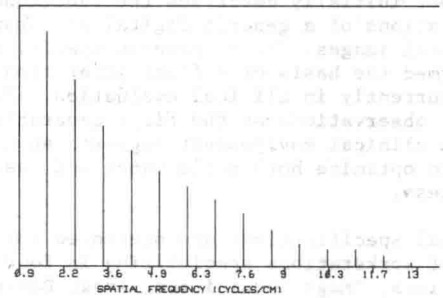


FIGURE 5: AMPLITUDE TRANSFER FUNCTION

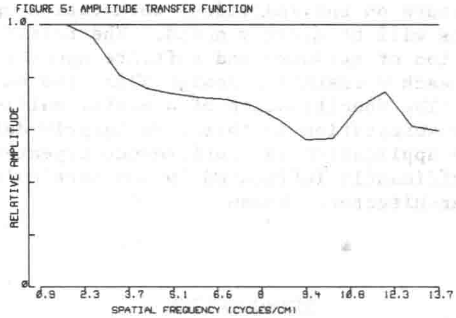
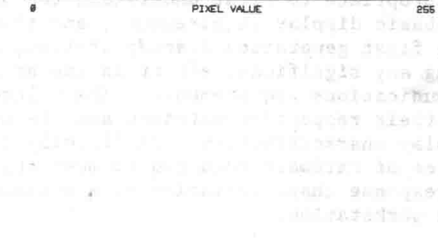


FIGURE 6: SCREEN LUMINANCE VS. PIXEL INTENSITY



FUNCTIONAL SPECIFICATIONS OF A USEFUL DIGITAL MULTIMODALITY IMAGE WORKSTATION

By M. J. Gray and H. Rutherford

MEDINET, INC.

ABSTRACT

This paper initially describes the functional specifications of a generic digital workstation for medical images. These generic specifications have formed the basis of a first generation PACS design currently in clinical evaluation. Preliminary observations of the first generation system in a clinical environment suggests an opportunity to optimize both performance and cost effectiveness.

Functional specifications are presented for a series of workstations specializing in four major applications, Image Acquisition, Image Review, Image Processing, and Image Archiving. The importance of performance and the impact of system architecture on the individual workstation specifications will be clearly noted. The relative composition of hardware and software specialization in each workstation design will also be described. The specification of a useful multimodality workstation is therefore largely determined by application and performance expectations and significantly influenced by the particular system architecture chosen.

INTRODUCTION

The Picture Archiving and Communications System has been a subject of increasing interest since the first PACS symposium in 1982 at Newport Beach. In addition to archiving and communications the acronym should include image display and acquisition, since these also are important components of this Digital Video Diagnostic System. It is interesting to note that the development and implementation of the archiving and communications components is not as far along today as the display components. This lag is not entirely due to technology.

It is appropriate to first understand the clinician's basic display requirements, and then assemble a first generation display station, before investing any significant effort in the archiving and communications requirements. The volume of images, their respective matrices and the particular display characteristics will directly affect the choice of hardware required to meet the expected response characteristics of a successful clinical workstation.

A first generation multimodality acquisition and review system is currently under evaluation at two medical centers. The results of this evaluation are expected to aid in the design of second generation workstations that are better suited to specific tasks. This refinement of the prototype system through functional specification is expected to result in a cost-effective, component approach to the total digital imaging system. By the time a clear understanding of display function produces the specialized workstation, the appropriate communications and archiving technology will be available.

THE GENERIC DISPLAY STATION

The design specifications of a prototype medical image workstation were presented by the authors in two earlier papers[1,2]. The major concerns of this prototype development were: to produce a high quality, flicker free display; to match the display capabilities of the digital system to those of the analog lightbox; and to pay particular attention to response rates and user interface. The results of this design effort are represented by the first generation system referred to as Gould's GS 1000. The preliminary evaluations of the GS 1000 are reported elsewhere[3]. Display formats and enhancements have been previously described[2].

The initial modifications to the GS 1000 design suggested by the clinical sites are best understood through the analysis of a workstation model, a so called Generic Display Station. The clinician's impressions of the workstation usually went no deeper than descriptions of the basic features which they use to display the images. Development of the second generations workstations will result in specialization of these basics at the technical level below the concern of the clinician.

The Generic Display Station will consist of the following nine components described below. A diagram of the GS 1000 is presented in Figure One as an example.

1. DISPLAY SUBSYSTEM. The display component must accommodate a range of image resolutions. The number of individual images displayed and the memory requirement of the display subsystem simultaneously depends on the display resolution, the number of monitors, the original resolution of the images, and the resolution of the images as presented.

2. COMPUTER SUBSYSTEM. The generic workstation must be supported by a processor. This processor may be either dedicated or timeshared. The

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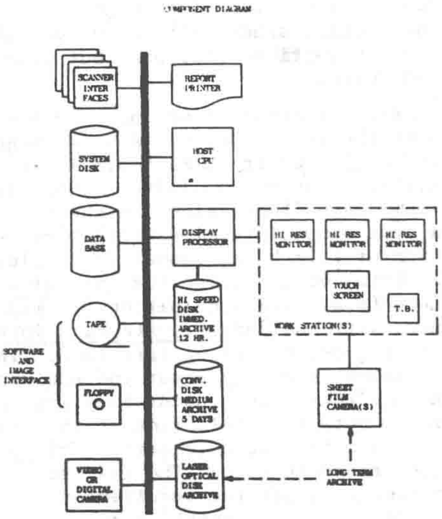

FIGURE ONE

assigned computer resource will then execute the applications software package of the workstation. The size and complexity of this software package and the necessary hardware to support it are both subject to specialization.

3. DATA STORAGE SUBSYSTEMS. There are three major storage requirements for the workstation: Software, Image Data, and Non Image Data. The overall system architecture will determine whether the software must be replicated at each workstation. Even with a shared and networked image archive, there is a clear need to provide local image storage for the workstation. This reduces the display memory requirement and improves the response rate. The size and type of workstation storage is determined largely by the number of images and reports that must be available, the length of availability, and the necessary response rate. The types of devices available for this requirement are floppy disk, magnetic tape (reel or cartridge) removable magnetic disk, Winchester type disk, high speed (Real-Time) digital disk, and video or digital laser disk.

In addition to short term storage (1-5 days) those devices with removable media provide a method of image acquisition by the workstation and off-line image archive. The laser disk provides the most cost-effective method for long term storage, but an analog film camera is the current technique for image archiving. Figure One summarizes the various types of data storage devices that were chosen for use in the GS 1000.

4. IMAGE ACQUISITION SUBSYSTEM. The workstation will have to acquire images from the original medical imaging devices and from the image archive. The technique for acquiring original data can be either digital or video.

Video techniques for the acquisition of images from RS170-and-RS330 compatible Ultrasound and Nuclear Medicine devices are potentially cost-effective alternatives to digital acquisition without significant loss of data quality. The digitization of film-based images using a video camera may also be an acquisition technique, if the limitations of the camera's spacial and grey scale resolution are acceptable.

The digital acquisition techniques for acquiring images from scanners or archive include the standard digital interface under joint industry development, the higher resolution digital cameras for film-based image digitization, and magnetic tape and floppy disk transfer.

5. INFORMATION MANAGEMENT SUBSYSTEM. The management of information associated with image files as well as the entire operation of an imaging department can be handled by a workstation's computer resource. The appropriate computer resources are determined by the scope of this information management and the number of individuals who must have simultaneous access. The more extensive the scope of the management task, the larger the computer resource needed (such as the VAX class machine used in the GS 1000). Alternatively, the stand-alone workstation requiring only the management of a small volume of on-line images and almost no department management might easily be supported by a minimal processor.

6. REPORTS SUBSYSTEM. The workstation is the ideal place for the creation and subsequent review of the diagnostic report. The best approach to reports is the use of a word processor package. Either the clinician or the support personnel can actually input the report using the workstation keyboard. The report is displayed as text on the terminal, not as an image on the display monitor. The report should be associated and stored with the images. A letter quality printer would be a useful option for the workstation so traditional archiving and distribution methods can be utilized.

7. IMAGE DISTRIBUTION SUBSYSTEM. The workstation will be required to share image and report information with numerous subscribers on either a simultaneous or first come, first serve basis. The traditional concept of digitally networked workstations is one approach. The performance characteristics of the network will determine the usefulness of this approach. The use of video distribution techniques including computer controlled switching and broadband or baseband video networks is another approach. The amount of display resource in the workstation will determine the degree of simultaneous access and the overall acceptability of the video approach.

8. NETWORK INTERFACE. Whether the workstation is based on a centralized or peripheralized architecture, there should be an interface to the other workstations that will eventually be added to the department. Specialization will produce a variety of products that will ultimately be networked together to form the totally digital department. These individual workstations might feature different hardware and software. Their compatibility then becomes the responsibility of the network and interface products. The overall control of the network or information management system can then be supplied by any of the workstations with the appropriate host computer.