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**AN INEXPENSIVE ELECTRONIC
VIEWBOX**

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An Inexpensive Electronic Viewbox

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ABSTRACT

An "electronic viewbox" is described that has been designed to meet the demand for a modestly priced soft-copy display for radiology. Issues associated with spatial resolution, intensity resolution, image magnification, user interface, digital communications and possible applications are discussed.

1 INTRODUCTION

The increased prevalence of radiological imaging devices that produce digital output calls for a means to display the resulting images in soft-copy form without sacrifice of the image's inherent spatial and intensity resolution. Widespread adoption of such digital display techniques requires the availability of an inexpensive replacement for the ubiquitous light box to insure that no loss in viewing convenience accompanies the change from hard-copy to soft-copy presentation. This paper describes the development of an "electronic viewbox", or EVB to meet the demand for a modestly-priced digital soft-copy display. Our design goals were: economy, flexibility, high-quality presentation, light-box functionality, and modular assembly of multiple displays.

2 SYSTEM DESCRIPTION

A prototype of an electronic viewbox has been constructed with the following characteristics:

Spatial resolution of display:	1024 by 1024 pixels
Intensity resolution of display:	8 bits (monochrome)
Refresh rate of display:	60 Hz (non-interlaced)
Active display area:	8 by 8 inches (adjustable tilt)
Intensity storage:	1024 by 1024 by 11
Overlay storage:	1024 by 1024 by 1
Gray scale mapping:	2048 by 8 LUT (updated at 15 Hz)
Image transmission:	LAN (Ethernet-10 Mb/s)

To achieve the intensity resolution needed for many radiological images requires an image memory with 11 bits of storage for each of the display screen's 1,048,576 pixels (1 Mpixel). Both CT and MR imaging devices now produce 11-bit pixels and future digital radiography devices are likely to follow suit. Since the human eye is incapable of appreciating more than 7 bits of intensity information from a CRT display screen [1], an adjustable mapping from the recorded pixel value to the displayed value is required if all of the recorded information is to be made available for viewing. In the prototype EVB this contrast adjustment is accomplished by a look-up table (LUT) that can be updated at 15 Hz with new window level and width parameters.

In addition to providing interactive contrast adjustment, we wished to experiment with pan and zoom transformations of the image. The microelectronic parts available at the time the prototype EVB was designed

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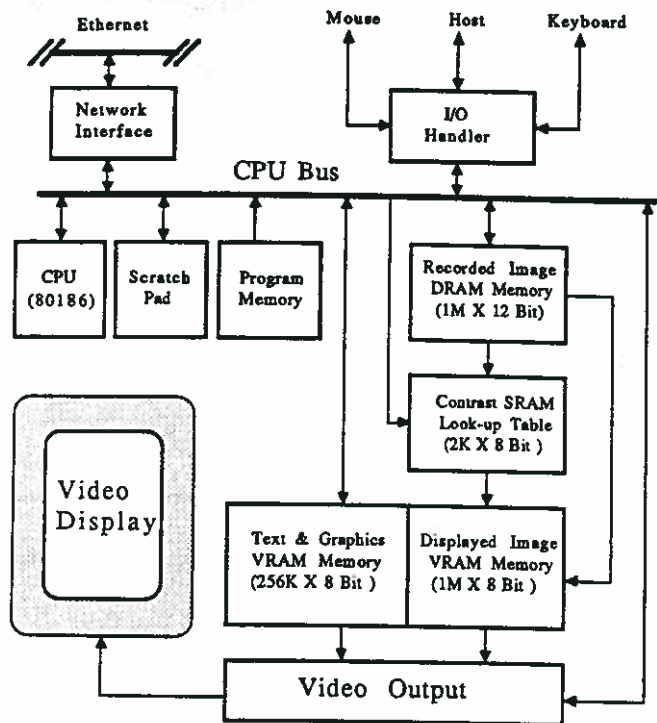


Figure 1. Block diagram of electronic viewbox showing data paths.

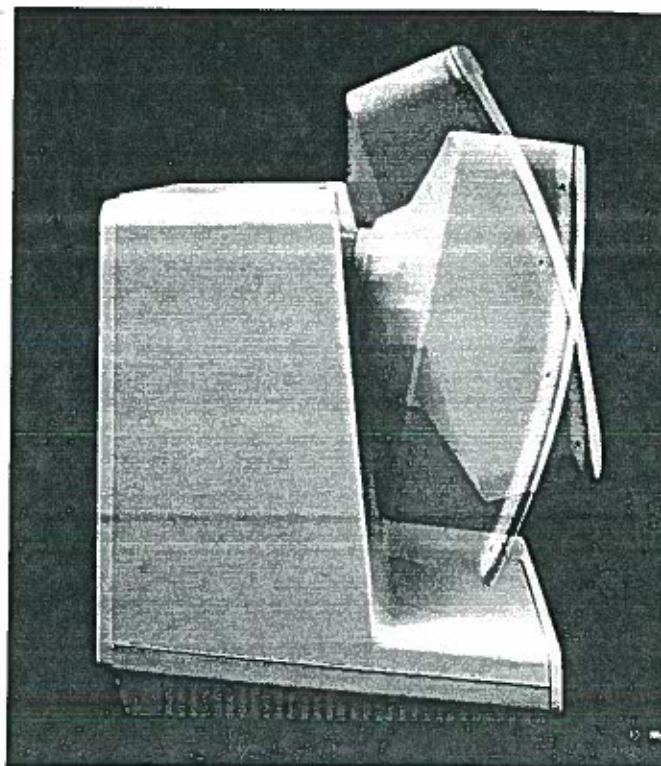


Figure 2. Side view of electronic viewbox showing tilting mechanism.

were not fast enough to make the contrast, pan and zoom transformations as pixel values were passed from the display buffer to the video output circuit. For a 60 Hz, 1 Mpixel display a pixel production rate (dot clock) of 87 MHz is required. Bilinear interpolation algorithms [2] that we wished to use for pan and zoom require four multiplications, three additions and two new pixel values from memory to compute each interpolated pixel for display. Even with state-of-the-art components such a design would require a very high degree of parallelism.

For these reasons we chose a prototype design that included an 8-bit displayed image memory and a separate 12-bit recorded image memory. The display is refreshed at a 60 Hz rate directly from the displayed image memory which, in turn, is updated at a 15 Hz rate from the recorded image. This slower update rate is rapid enough to produce a smoothly changing display and yet reduces the requirements for parallelism by a factor of 4. In the prototype EVB, pixel interpolation was programmed and did not provide the speed needed for interactive pan and zoom, but this arrangement did allow for some experimentation.

Figure 1 is a block diagram of the prototype EVB indicating the recorded and displayed image memories. The recorded image memory contains 11 bits per pixel of gray-scale information and a single bit per pixel used for a bitonal graphics overlay of the image. When set to one these overlay bits can replace the gray-scale pixel value with a fixed intensity making it possible to display pointers, icons, text and curved outlines indicating regions of interest.

The prototype EVB is mounted in a cabinet (Figure 2) that features a novel tilting screen so that the best viewing angle can be easily obtained. The screen has a diagonal measurement of 15 inches and an active display area of 8 by 8 inches. A 2 inch high text and graphics area can be added at the bottom of the screen increasing the active display area to 8 by 10 inches. This optional, 2-inch region of text and graphics is completely independent of the text and graphics controlled by the overlay bits stored in the recorded image memory. Switching to the 8-by-10 mode causes the screen refresh rate to drop to 50 Hz. In either 8-by-8 or the 8-by-10 mode the display

has a resolution of 128 points per inch.

All of the digital circuitry is mounted on a single vertical board at the rear of the cabinet. Analog and power supply subsystems are mounted on the sides and bottom of the cabinet, well clear of the base of the CRT. Connections at the rear of the cabinet are to an RS-232C port, an Ethernet port, a pointer device (mouse or trackball), a keyboard and electric power.

3 SPATIAL RESOLUTION

For digital radiographs (such as the abdomen shown in Figure 3 on the next page), images must be displayed at high resolution to present necessary detail. A minimum resolution of 1024 by 1024 pixels seems to be mandatory, but the inherent resolution of the original digital radiograph, 2048 by 2048, is desirable. This higher resolution implies a dot clock of 400 MHz, more than four times the rate for the prototype EVB. A nonlinear relationship exists between the number of pixels displayed and the dot clock rate because as the CRT horizontal oscillator frequency increases, the flyback time decreases more slowly than does the time required for the active portion of a raster line. As a consequence, modestly-priced 2048-by-2048 displays are unlikely to make their appearance for a few years. The prototype EVB, on the other hand, gives adequate resolution with technology that is readily available now. Figure 3 shows two halves of two abdominal images photographed directly from the screen and gives some impression of the display quality, but does not adequately convey its true resolution because of the limitations imposed by halftone reproduction.

4 INTENSITY RESOLUTION

The transformation from 11-bit to 8-bit integers performed in the LUT of Figure 1 may appear unnecessary. Why not perform the intensity transformation just once before the image is displayed and thereby avoid the need for a fast LUT? Figure 3 shows two settings of the window level that bring out different features of the image not visible in any one global intensity mapping. Contrast enhancement techniques such as adaptive histogram equalization (AHE) [3] can improve contrast in a regionally specific manner that overcomes the need for multiple widow settings, but radiologists are likely to continue to wish to retain the option to see and manipulate the original data even when they also use AHE displays regularly.

The ability to manipulate interactively the window level and width is a feature that we believe to be advantageous, but no clinical or psychophysical studies have been carried out to verify this conjecture. Experience with widow level and width controls on CT and MR scanners lend support to this conjecture and strengthen the need for a system that yields smooth hand-eye coordination during contrast adjustments. Update rates of 15 Hz seem to be sufficient for this purpose.

5 IMAGE MAGNIFICATION

Magnifying an electronically presented image (zooming) can replace, to some extent, the radiologist's ability to obtain a more detailed view of a portion of a film by moving closer to the light box. True, some context is lost in zooming and the movement of a zoom control is less intuitive than moving one's head. Even with these limitations in mind, it would seem that the ability to magnify a portion of an image would be quite useful. So far, systems that carry out zoom operations by pixel replication [4] have not been widely accepted. With pixel replication no new information is presented to the viewer, magnification factors are limited to integers (usually powers of two) and the uniform value of adjacent pixels may give a checkerboard appearance to the display.

Higher order interpolation algorithms (bilinear or bicubic [2]) can reduce the problems cited for the pixel replication approach, but can never restore the information lost by the sampling process. If the original image is low-pass filtered prior to sampling, a bilinear or bicubic interpolation can approximate an ideal reconstruction of the sampled image. Bilinear is computationally simpler, but less accurate than bicubic interpolation. Bicubic algorithms typically require twice as many multiplications as bilinear and double the memory bandwidth.

In Figure 4 we compare zooming by pixel replication and by bilinear interpolation. The improvement obtained with interpolation is easy to recognize and we believe worth the extra circuit complexity required to achieve

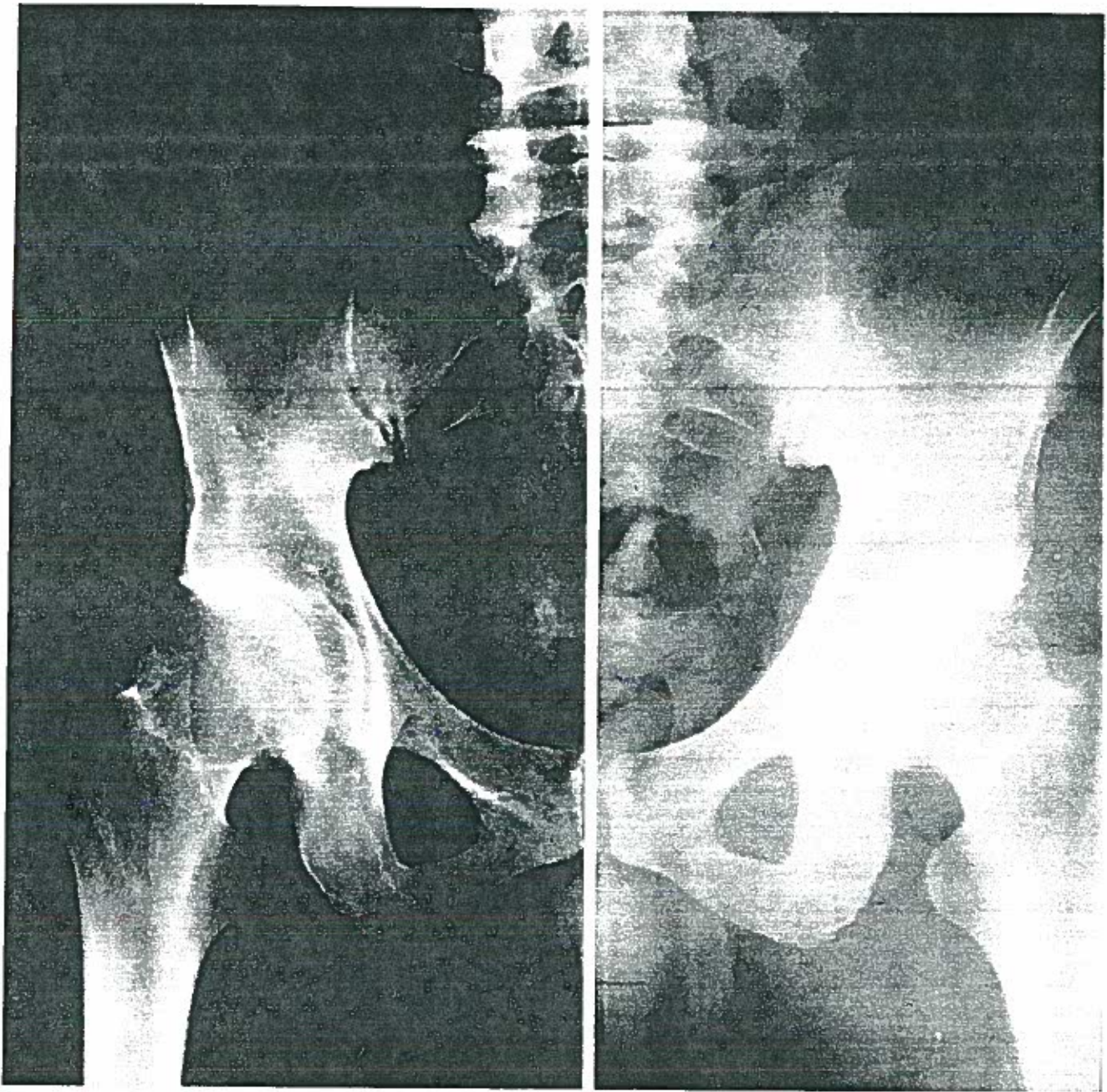


Figure 3. Two photographs of the EVB screen displaying an abdominal radiograph. The figure is split in the middle to show the contrast adjusted for bone (left half of screen only) and adjusted for soft tissue (right half of screen only).

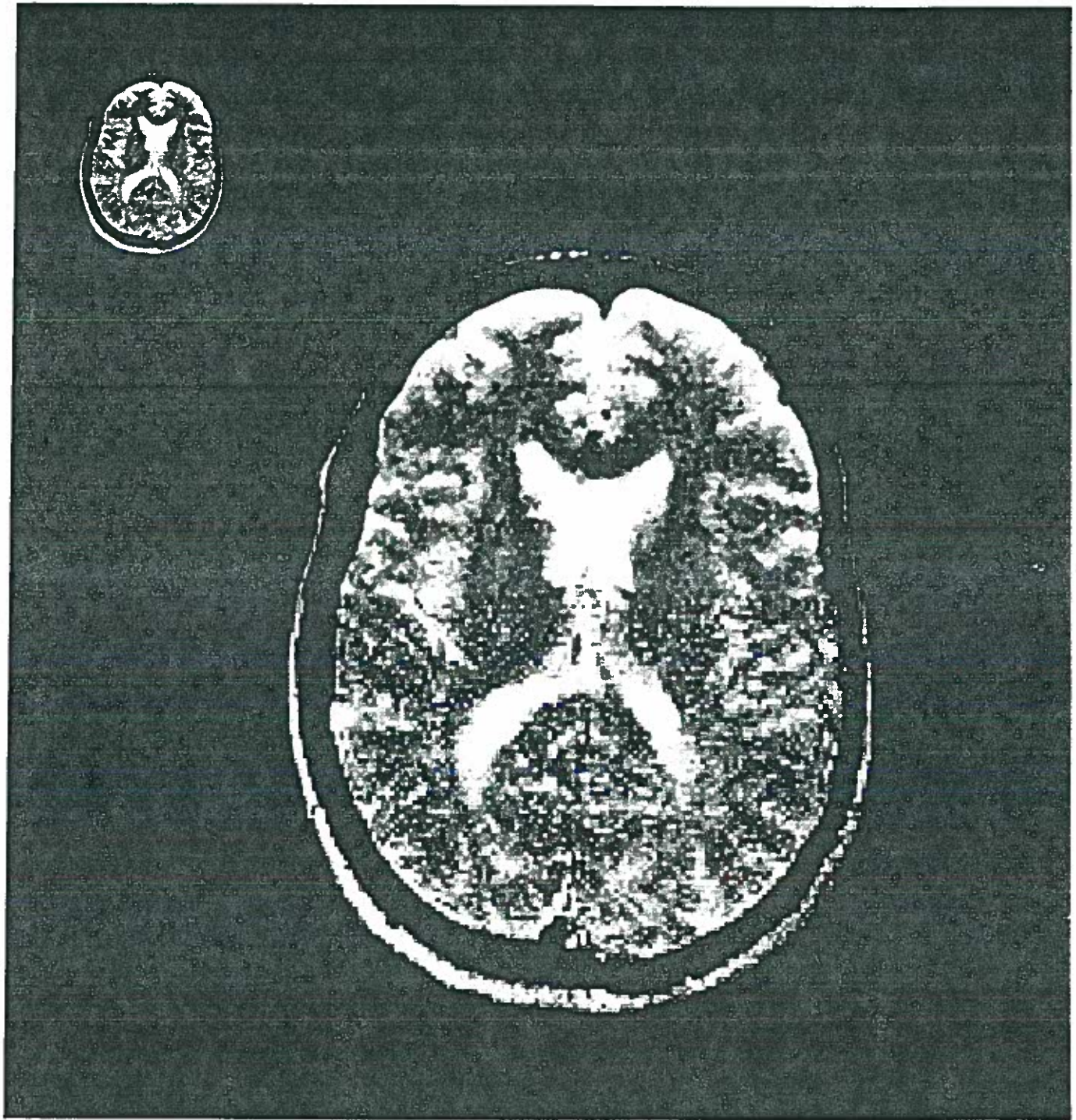


Figure 4. A magnified MR image of a section of the brain (zoomed by a factor of 4) with the original shown at the upper left. The bottom half of the magnified image is computed by pixel replication while the top half is computed by bilinear interpolation.

15 Hz update rates. At this time it appears that bicubic interpolation at similar rates is impractical if the system is to remain modestly priced.

6 INTERFACE ISSUES

The user interface with the prototype EVB utilizes a keyboard and a pointing device for input, the full 8 by 10 inch active screen area for output and software that operates in the Intel 80186 processor for interactive control. For example, with a mouse the window level and width can be controlled through a slider display. Trade-offs between the keyboard and the mouse for image identification have yet to be examined, but substantial keyboard input should probably be avoided to make the system attractive to radiologists.

The transmission of digitized images to the prototype EVB is by means of an Ethernet channel, a compromise choice between the competing goals of wide bandwidth, low-cost and easy adaptability to image sources. All packets are 1024 bytes in length and each transmission begins with a control packet followed by the appropriate number of image data packets. A full resolution (1024 by 1024 by 12) image is transferred as 2 megabytes (2 bytes per pixel) requiring 2049 packets and about 7 seconds from disk to display using a MicroVAX host. Under similar circumstances, a 256 by 256 by 8 image requires 129 packets and less than a second for transmission. At the full Ethernet channel bandwidth (10 Mb/s) these transfers would require only about 2 seconds and 1/8 second, respectively. Some improvement in the measured transmission time is possible, but packet handling in the I/O system of the host and contention on the Ethernet will limit the responsiveness to times substantially longer than those associated with the 10 Mb/s bandwidth.

Although these transmission times are not ideal for full resolution images, they are satisfactory for CT, MR and nuclear images and do bring the performance of the prototype EVB into a range that will be useful experimentally for larger images. Ultimately, a wider bandwidth LAN will be required to achieve the responsiveness that radiologists desire for high definition images.

In addition to the Ethernet channel and pointer device which are associated with image selection and manipulation, a separate terminal subsystem consisting of an RS232C port, a keyboard and a 10 row character display is available for the presentation of alphanumeric information.

7 APPLICATIONS

The prototype EVB can stand alone in an emergency room, an operating room, an intensive care unit or on a physician's desk. The functions familiar to the user of a light box are all available plus the option to take advantage of adjustments in image contrast. Through the RS232C port the EVB can be connected to a workstation or a personal computer. Software to take advantage of this option is yet to be written.

The assembly of EVBs into a multiviewer is also contemplated. Control of an array of EVBs by a single computer is easily achieved through their Ethernet connection. A multiviewer with more than about a half dozen screens is probably impractical because of the limited network bandwidth now available.

Early reaction by clinicians to the prototype EVB has been positive. It has led to the initiation of a second generation design that includes interactive pan and zoom with bilinear interpolation. Impressions of the display of digital radiographs of the chest and abdomen suggest that the resolution is adequate for clinical use. A carefully controlled clinical evaluation, however, will be necessary to provide a definitive assessment of the adequacy of the EVB's resolution for high definition images.

8 ACKNOWLEDGMENTS

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