COMPUTER TECHNOLOGY

A vector graphic CRT display system

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A vector graphic CRT display system for research in visual information processing is described. The vector graphic processor includes a 4K-byte display memory. The processor communicates with the controlling computer via a serial channel. The system is capable of exposure durations below 1 msec, and it allows on-line generation and modification of display files during an experiment. Brightness can be controlled separately for each vector of a picture. A graphic display editor in FORTRAN IV for interactive editing and debugging of display files has been developed.

The purpose of this paper is to describe a vector graphic CRT display system that is suitable for research on visual information processing and for computer graphics applications. The system can be implemented on any computer that supports a standard serial interface.

Our CRT display system was designed to meet the following requirements: (1) a minimum display time below 1 msec, (2) presentation of several pictures in rapid succession (e.g., for visual masking or apparent movement), (3) flexible brightness control within a picture, (4) on-line generation and modification of display files during an experiment, and (5) achievement of flicker-free display of at least 2,000 vectors with a fast-decaying phosphor. In addition, the display system should impose only moderate demands on the working memory of the controlling computer, and the display processor should communicate with the computer via a standard serial interface.

In designing a CRT display system (Giloi, 1978), a choice can be made between the line-scanning and the random-access modes (Green & Shwartz, 1978). In the first mode, each of the 256 by 256 or 512 by 512 or 1,024 by 1,024 display points must be scanned line sequentially, so that scanning all display points will take 20 msec or longer with a refresh rate of 50 Hz. This defines the minimum display time, which may be too long for some applications that are critical in time. Moreover, flexible brightness control would impose considerable demands on the working memory. Within the random-access mode, the point-plotting mode and the vector mode can be distinguished (Prince, 1971). In the point-plotting mode, a picture is made up of points, and only these points need to be scanned during display. In the vector mode, a picture is made up of isolated and/or concatenated vectors, and only the start/end coordinates and brightness information of each vector are required for display.

The main disadvantage of the point-plotting mode is

the requirement of one memory cell for each point of a picture, which calls for a large working memory. Furthermore, complex pictures require very fast digital-to-analog converters, which are quite expensive. With slower digital-to-analog converters, the number of points of a complex picture may be too large for very brief exposure durations. Isolated points can also be generated in the vector mode. However, analog vector generation in the vector mode requires more memory than analog point generation in the point-plotting mode, and maintaining a constant brightness level with varying vector lengths is more difficult in the vector mode than in the point-plotting mode. We have chosen the vector mode because the demands on the working memory are considerably reduced, briefer exposure durations can be achieved, and the hardware of a vector graphic processor is less expensive than that of a point-plotting processor having the same efficiency.

DESCRIPTION OF THE DISPLAY SYSTEM

Hardware

The display system consists of the vector graphic processor, a serial interface for communication with the controlling computer, and an X-Y display. Figure 1 shows the vector graphic processor, which is the essential hardware design. The processor occupies one digital and one analog board in double European Board Card (EBC) format. The data (i.e., commands, addresses, and vector coordinates) are transmitted via the line receiver and are converted from serial to parallel code by a universal asynchronous receiver and transmitter (UART). The data are sent via a buffer first to the command decoder and then to the address counter and the display memory. Loading of the display memory can occur while contents of other areas are displayed. The data are sent from the output buffer as coordinates to the X- and Y-axis slew circuits, as jump addresses to the address counter (read), or as brightness information to

Figure 1. Components of the vector graphic processor.

Figure 2. X- and Y-axis slew circuits.

the intensity-control unit. The control logic (output) supervises the blanking/unblanking of the screen.

The X- and Y-axis slew circuits (Garcia, 1976) are outlined in Figure 2. The generation of a vector takes two cycles. In the first cycle (C1), the 8-bit digital-to-analog converted start coordinates X_s and Y_s are

stored via the analog switch S1 in a sample-and-hold circuit. Switch S2 sets an integrator to its initial value. In the second cycle (C2), the digital-to-analog converted end coordinates X_e and Y_e are transferred to a differential amplifier. The difference between the voltages corresponding to the start and end coordinates is sent

via Switch S3 to the integrator, which integrates the voltage between the initial value and the end value of the coordinates.

Data Structure

The display data are stored in the display memory. A picture consists of points and/or vectors. A vector is defined by its start and end coordinates. Separation of two vectors (i.e., nonidentity of the first vector's end coordinates and the second vector's start coordinates) is indicated by a vector separation identifier. If two vectors are concatenated, then only the end coordinates of the second vector are required (Figure 3).

A set of separated or concatenated vectors can be organized into a block. A block ends with a block-end identifier, followed by a chaining address. The chaining address causes an absolute jump to the beginning of either the same or a different block. The chaining address includes the brightness information of the addressed block (Figure 4). Sixteen brightness values either in linear or in logarithmic scaling can be selected.

Flicker-free presentation of a picture requires that the picture be refreshed at least 40 times/sec. Therefore, one

Figure 3. Representation of a concatenated vector in the display memory.

Figure 4. Block structure.

Figure 5. Representation of a graphic picture. Activated (displayed) are Blocks 1, 2, 3, and 4. Block 5 is deactivated.

or more blocks must be chained into a sequence, so that the jump address of the last block points to the first block for refreshing (Encarnacao, 1975). This cyclic chaining, which yields a ring structure, represents a graphic picture (Figure 5).

Several graphic pictures can be stored in the display memory, but only one of them can be activated (displayed) by a control command from the computer at a given time. During the display of a picture, other pictures can be loaded into free areas of the display memory, or single vectors, brightness information, and jump addresses of already loaded pictures may be overwritten. Figure 6 shows a graphic picture displayed on the screen.

Specifications of the Display System

Communication between computer and vector graphic processor is by a serial channel (RS 232 C). The transfer rate is switch selectable from 19.2 to 153.6 kbaud. Transfer time per vector is 325 microsec. Display memory is 4K bytes and is easily expandable to 16K bytes. Capacity of the display memory (4K bytes) is 2,000 vectors or 600 blocks consisting of one vector each

Figure 6. Display of a graphic picture on the screen.

(16K bytes: 2,400 blocks). Resolution is 254 by 254 lines (8 bits).¹ Refresh rate is 40 Hz for 2,000 to 3,500 vectors, depending on the slew rate for one vector. A picture consisting of 10 vectors is displayed once in 100 microsec. Generation time for one vector is 4 microsec (adjustable between 3 and 10 microsec). Generation time is independent of vector length. Minimum exposure duration under computer control is 200 microsec. Repeat reliability for points and vectors is total. Barrel distortion is less than or equal to one-half of the least significant bit (LSB) (i.e., $\leq .5$ mm for total picture). Error in parallelism of lines is less than or equal to .5 LSB. Analog X-Y voltage is between +1.2 V and -1.2 V (adjustable up to ± 2.5 V). Z-axis voltage is adjustable between .5 V and 5 V (TTL). Brightness levels range from dark to maximum intensity of the display. Alphabetic characters are software generated by DISPED (see below); hardware generation is not possible. Labor costs include material costs below \$500 and about 30 working hours for mounting and testing the three print boards. Print boards are planned for 1981. X-Y display is accomplished via a dual channel oscilloscope with Z-axis input and bandwidth of greater than or equal to 20 MHz. We use a Hewlett-Packard X-Y display (Model 1300 A) with P31 phosphor. Implementation is via a PDP-8/e with 32K words of working memory, dual floppy-disk drives, and a LAB 8/E package consisting of a programmable clock, digital input/output, and analog input.²

Software Support

A graphic editor (DISPED) has been written in FORTRAN IV. DISPED allows interactive editing of display files so that file manipulations can be monitored on the X-Y display. A display file consists of

blocks with chaining addresses and brightness parameters.

With DISPED, the user can perform the following operations: (1) manipulations of the display-file pointer position (absolute and relative, across vectors and blocks); (2) deletion, insertion, replacement, and appending of blocks, vectors, single points, single words, or alphanumeric strings in the display file; (3) generation of alphanumeric strings and selection of character size and of the first character's position; (4) translation, scaling, and rotation of display-file contents and copying within the display file; (5) fade in/out of X- and Y-axes or of a grid on the screen; (6) request for status information about display-file pointer position, display-file length and contents of selected display-file positions; (7) insertion of chaining addresses and of brightness parameters; (8) input and output of edited display files to and from disk; (9) naming a display file; (10) printing a display file on a line printer; (11) loading of display files into the display memory and activation of a graphic picture on the X-Y display; (12) selective manipulation of display memory contents, brightness parameters, and chaining addresses; and (13) command string operations.

Each command of DISPED consists of two characters. If the editor of DISPED is ready for a new command, an asterisk is written on the console terminal. Table 1 illustrates the generation of a display file corresponding to a square, which is then transformed (scaled) into a rectangle. The generated display file is written on the disk as SQUARE.DA.

The basic commands of DISPED are quite easy to learn because the more complicated operations such as management of chaining addresses can also be performed automatically by DISPED. In addition, DISPED includes a HELP subroutine that gives the user information about each command.

DISPED is running under the operating system OS8 V3-D. DISPED can be used with any other computer system with a FORTRAN IV compiler that provides for dynamic file handling.³

The only software component that is specific to the controlling computer system is the device handler for data transfer between the computer and the display processor via the standard serial interface. This device handler can be generated by modification of the Teletype handler.

DISPED requires one floppy or hard disk with at least 75K-byte capacity for the background storage. The various DISPED subroutines are organized into several overlays that occupy about 24K words of the working memory. The maximum length of a display file is 2,000 X-Y coordinates, which can be increased according to the working memory of the computer.

For control of the experiment, FORTRAN II is used as a programming language. Several subroutines in FORTRAN II are available for time-controlled picture presentation and for the selective overwriting of display memory contents during an experiment. For example,

Table 1
Generation of a Display File Corresponding to a Square With DISPED

Command	Comment
<u>_R</u> DISPED	Call DISPED
<u>&ED</u>	Call editor of DISPED
<u>*AV</u>	Append vector to display file
50,50	Starting point
50,-50	X-Y pairs in absolute coordinates (Point 0,0 is center of screen)
-50,-50	
-50,50	
50,50,#	End point, end of vector (#)
<u>*IA</u> 2000,14	Insert chaining address (2000) and intensity parameter (14)
<u>*MS</u>	Move pointer to start of display file
<u>*SC</u>	Scale
<u>SCALING AREA</u> 0<= <u>X</u> <=5.1	Range of scaling factors
<u>SCALING AREA</u> 0<= <u>Y</u> <=5.1	
<u>ENTER</u> XSCFAC, YSCFAC: 2.,1.	Transformation into a rectangle (horizontal extent = 200, vertical extent = 100)
<u>*WF</u>	Write display file on disk
<u>ENTER</u> FILE-NAME: SQUARE.DA	File name: SQUARE.DA
<u>*EE</u>	End editor
<u>&GB</u>	Go back to monitor
<u>_</u>	Back in monitor

Note—The characters written by the monitor or by DISPED are underlined.

time-controlled exposure is achieved by the following statement:

CALL SDPT (ADDR, CLKFR, CLKNO).

According to this statement, the picture with the start address ADDR in the display memory will be activated for the duration $\text{CLKNO} \times \text{CLKFR}$, and CLKFR can be set equal to 10 msec, 1 msec, or 100 microsec.

CONCLUDING REMARKS

Two problems occur with our display system. First, dynamic generation and loading of display files during an experiment requires a fast central processor and a high transfer rate from the computer to the graphic controller. For example, smooth apparent movement can be achieved with a sequence of at least 24 pictures/sec. Thus the display time of each picture must not exceed 42 msec. If the display memory is loaded with the succeeding picture during this time, then the complexity of the picture must not exceed 130 vectors with a transfer rate of 153.6 kbaud. Second, the brightness of a vector decreases with its length and with the total number of vectors in the picture. However, brightness can be held constant, first, by decomposing each vector into unit-length segments, second, by varying the brightness parameters, third, by different vector scanning rates, and fourth, by introducing invisible dummy vectors that equalize the number of vectors over different displays.

Considering the fact that the material costs are below \$500, one can conclude that the vector graphic processor is relatively inexpensive. The display system

is also very versatile and, therefore, suitable for various experimental applications. The graphic display editor DISPED makes plentiful provisions for display-file generation and debugging. By using DISPED and the FORTRAN II subroutines for display, timing, and response acquisition (Arend & Wandmacher, Note 1), the programming of a new experiment can be done within a few hours.

REFERENCE NOTE

1. Arend, U., & Wandmacher, J. *Laboratory subroutines in FORTRAN II for LAB 8/E of PDP-8/e*. Manuscript in preparation, 1981.

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NOTES

1. A 10-bit resolution would require serious changes of the control logic.
2. We are preparing the implementation on a newly acquired DEC PDP-11/23 system.
3. In the case of OS8, the corresponding subroutine for dynamic file handling is the subroutine USR from DECUS.

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