METHODS & DESIGNS

Optical and electronic systems for spatial and temporal analysis of video images

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In this paper are described two systems for spatial (two-dimensional coordinates) and temporal analysis of video images. In the optical version, the Apple IIe generates a pointer on an Apple monitor; the pointer is then superimposed on the video image of a second video monitor, by reflecting the pointer with a half-silvered mirror. In the electronic version, a special card was designed for the Apple IIe to generate a pointer directly on the other video monitor. Both systems use the same software. The procedures of spatial and temporal data acquisition and storage are described as well as the reading, writing, printing, removing, listing, chaining, and dating operations of the digital and graphics files.

In behavioral research, the problems raised by spatial and temporal analysis of video images generally involve determining the relative positions of several points, computing the spatial characteristics among the points (i.e., distances, angles, directions, orientations, trajectories, areas, etc.), and recording the changes over time of these spatial characteristics. Such analyses require two basic pieces of equipment: a timer, and a video image digitizer. The timer records the occurrence of the events; the digitizer converts some portion or all of the video image into digital values.

There are numerous commercially available systems that allow accurate two- or even three-dimensional spatial analysis of video images (see, e.g., Poizner, Wooten, & Salot, 1986). Nevertheless, there are also many laboratories where spatial analysis of video images remains rudimentary (e.g., applying a transparent matrix onto the screen of the video monitor). The main reason for the gap between the most recent techniques and the methods still used by researchers is financial. Because of this, we have developed two different systems. The first, based on an optical video-computer interface, requires only the purchase of a half-silvered mirror or any analogous optical interface. The second is based on an electronic-video-computer-card interface. Both systems use the same software; each one can be used independently.

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VIDEO-COMPUTER INTERFACING PRINCIPLES

To create the optical system, a pointer (2 orthogonal axes) is generated on the Apple monitor. This pointer is then superimposed on the video-image of another monitor by reflecting it with a half-silvered mirror. The Apple monitor and the other video monitor are placed at a 90° angle to each other in the same plane. The mirror is placed at 45° between the two monitors. In the electronic system, a pointer is generated directly on the video monitor; the card is automatically synchronized with the video signal.

MATERIAL

The essential hardware consists of an Apple IIe micro-computer (128K RAM) equipped with either a 6502 or 65C02 processor, an Apple monitor, two disk drives, and a compatible Apple ImageWriter printer (1982 model). A joystick or an Apple mouse can be added. The videographic equipment consists of a video recorder, a video monitor, and a video timer (providing a timebase on the tape).

The optical interface is created simply, with a half-silvered mirror (50 × 50 cm) or any analogous optical interface (e.g., tinted perspex). The electronic card is built around the 6522 Rockwell processor (see Appendices A and B).

The program expects to find the printer interface card (serial or superserial) in Slot 1, the mouse interface card in Slot 4, and the video interface card in Slot 5.

SOFTWARE

The program is written in Apple Pascal 1.2, based on UCSD Pascal II.1 (Bréaud-Pouliquen, 1984; Grant &

Butah, 1985; Haut, 1983; Rouault & Girard, 1985a, 1985b). The Pascal system size is 128K. The program also uses Pascal Assembly routines (Collibri, 1986). Written on a single start-up disk, it presents the user with a menu of options (Figure 1).

On both the optical and the electronic systems, the software divides the Apple screen into a graphics portion and a text portion. Within a rectangular graphics window, a pointer (shaped as a + sign) is drawn. Within the text portion of the screen, information and commands are provided for the user. In the optical system, the vertical and horizontal positioning of the pointer is controlled with the keyboard, a joystick, or a mouse. The position of the pointer is defined in terms of x , y cartesian coordinates inside a frame 251 units wide and 161 units high. In the electronic system, the pointer, which is directly generated on the video monitor, can only be moved with the keyboard. The position of the pointer is defined in terms of x , y coordinates inside a frame 512 units wide and 280 units high.

DATA COLLECTION

Device Selection for Spatial Data Acquisition

The user is asked to define the device (i.e., either the optical or the electronic system) to be used for data collection.

With the optical system, three tools enable data collection: the keyboard, a joystick, or a mouse. In the keyboard acquisition mode, the x , y movements of the pointer are controlled by the left, right, up, and down arrow-keys. Combined directions (e.g., left and up) can be obtained by pressing the corresponding arrow-keys. The space bar stops the pointer's motion. The pointer's position is recorded by pressing the ESC key.

In the joystick acquisition mode, the pointer is generated by analog signals from a joystick connected to the standard Apple game port. The joystick is equipped with two potentiometers that deliver 0–5V. This voltage is converted to digital values from 0 to 255 along the vertical and horizontal axes. The joystick is operated in the "free-floating," instead of the "auto-centering," mode. The position of the pointer is again recorded by pressing the ESC key of the keyboard.

In the mouse acquisition mode, the program uses 6502 Assembly routines declared as external functions (Martel & Suy, 1985), which allow direct access to the primitives of the mouse interface card. The pointed position is recorded by clicking the mouse or by pressing the ESC key of the keyboard. In order for the three operating modes to function similarly, the pointer movements are converted into graphics points compatible with the Apple Pascal Turtlegraphics Unit.

In the electronic version, only the keyboard controls the pointer. It is used somewhat differently from how it is used in the optical version. The x , y movements of the pointer are controlled by left, right, up, and down arrow-keys. The speed of the movement is increased fivefold

by simultaneously holding down the open-apple key and the relevant arrow-key. Releasing of the arrow-key stops the movement. The pointer's position is recorded by pressing the ESC key of the keyboard.

Precautions in Spatial Data Acquisition

Spatial data acquisition involves selecting and freezing a video image, and then selecting a desired point on it. To achieve this, the user makes the mobile pointer and the desired element of the video image coincide visually. Several sources of error in measurement are possible.

With the optical system, the coordinates of the selected position may vary according to the user's head position. In order to minimize such variability, it is imperative to make the center of the mirror and the center of the graphics window coincide visually. The center of the window is defined by an x -shaped cross. The center of the mirror is defined by the intersection of two orthogonal axes. Within the same set of measures, it is equally imperative to keep the relative position of the mirror and the two monitors constant. With both the optical and the electronic systems, it is also important to keep the linearity and vertical size adjustment of each monitor constant within the same set of measures. Finally, the freezing of a video image never gives a perfectly stable image—a problem inherent in the pause mechanism of most video recorders. This instability impairs the accuracy of all video pointers (electronic or otherwise).

Accuracy of the Measures

The accuracy of the system was assessed as follows. A 10×15 cm plane test pattern was video-recorded (lens: 50 mm, distance: 1.5 m). The test pattern, which consisted of 10 scattered points, was placed on a frontoparallel plane relative to the camera. Five operators were instructed to measure the 10 points as accurately as possible. Each operator used each of the four acquisition modes: one mode for the electronic system (keyboard), three modes for the optical system (keyboard, joystick, mouse). In each acquisition mode, the points were recorded by pressing the ESC key. All the precautions described above were followed. After calibration, the measured x , y coordinates of the 10 points were transformed into physical coordinates and compared to their actual physical coordinates inside the test pattern. For each measure in each acquisition mode, an absolute angular error was computed along the x - and the y -axis (Table 1).

Time Data Acquisition

Two options may be selected: "timing" or "no timing." If "timing" is selected, the user has to state whether the number of points to be recorded per time unit is "constant" or "variable." If the choice is "constant," the user predefines the number of points (n) to be recorded in each time unit. Then, for every n points, the user must store the time value associated with these points. If the choice is "variable," the sequence CTRL-O CTRL-T enables the user to change the time unit at any time during the

Figure 1. Flowchart of the pointer program.

Table 1

Accuracy of the Pointing System: Mean Angular Error (in Degrees)
for the Four Acquisition Modes (50 Measures per Cell)

	System			
	Electronic	Optical		
	Keyboard	Keyboard	Mouse	Joystick
M_x	0.021	0.074	0.075	0.098
SD_x	0.014	0.049	0.061	0.058
M_y	0.025	0.049	0.069	0.089
SD_y	0.016	0.046	0.056	0.080

acquisition process. In order to register times for recorded points, the user reads the time value displayed on the video monitor, and then enters this value via the Apple keyboard. The following standard format is used: hours (from 0 to 23), minutes (from 0 to 59), seconds (from 0 to 59), and hundredths of seconds (from 0 to 99). If the "no timing" option is chosen, the user goes directly to the spatial data acquisition. In this case, no time value will be associated with the recorded spatial positions, and all time values (hours, minutes, seconds, hundredths of seconds) will equal 0 by default.

Digital Storage of the Positions

With both the optical and the electronic systems, two modes of digital storage are possible (Figure 2). In the first, labeled "without grid," the user is provided with an empty graphics window. The x , y coordinates of the points in the graphics window are stored. For the optical system, the x , y coordinates vary from 0 to 250 (x -axis) and from 31 to 191 (y -axis). For the electronic system, the x , y coordinates vary from 0 to 512 (x -axis) and from 0 to 280 (y -axis). In the second storage method, labeled "with grid," the user is requested to choose a total or a partial grid inside the graphics window. When the total-grid option is selected, the user has only to define the sizes of the columns (horizontal step) and of the rows (vertical step) of which the grid is composed. When a partial grid is chosen, the user must first determine the position of this grid within the graphics window (left, right, lower, and upper sides), and then define the sizes of the columns and the rows of this partial grid. In both the "total" and the "partial grid" options, the minimum size of columns and rows corresponds to five graphics points. In both "total" and "partial grid" options, the x , y coordinates selected remain those of the points of the graphics window. But the x , y coordinates of the stored points will be those of the column and the row of the grid at this position. Whatever the sizes of the columns or rows, and whatever the position of the partial grid, every position that belongs to the first column (from the left side) and to the first row (from the lower side) will be stored as $x = 1$ and $y = 1$. In the partial grid option, every position outside the grid is stored as $x = 0$ and $y = 0$.

Graphics Mode Storage

With both systems, different modes of graphics storage are available (Figure 2). First, each point may or may

not be represented by a small dot within the graphics window. The sequence CTRL-O CTRL-E enables the user to go back and forth between these two "echo" and "no echo" options (the initial state of this command is "no echo"). Second, a straight line may or may not be traced between two successive points. The sequence CTRL-O CTRL-D enables the user to go back and forth between these two "draw" and "no draw" options (the initial state of this command is "no draw"). All combinations of choices from the "echo/no echo" and "draw/no draw" options are possible.

Storage on Disk

Once the acquisition is completed, the sequence CTRL-O CTRL-Q enables the user to leave the creating option.

Two different files (digital and graphics) can be associated with the acquired data (Figure 3). The digital file is organized as an array of records. Each record consists of six fields: time values are associated with the recorded point (in hours, minutes, seconds, and hundredths of seconds: four fields), and with the x , y coordinates of the point (two fields). The graphics file stores only the information contained in the graphics window (which corresponds to the high resolution graphic page number 1, located from 8192 to 16383 memory address). The appropriate extensions (.DIGIT and .GRAF) are automatically added to the filenames of the digital and graphics files.

Data is automatically written to disk every 42 records (512 bytes) during the acquisition phase. Consequently, the maximum size of a digital file is limited only by disk capacity. Since a blank formatted disk consists of 274 unused blocks, and since a block may contain 42 records, the maximum size of a digital file is about 11,508 records.

Once the acquisition is completed, the user is asked to choose whether to save the digital and graphics files permanently. If the answer is "yes," the digital and graphics files are permanently written to disk and locked. If the answer is "no," the digital file, which may already have been written by the automatic saving procedure, is removed from the disk. Saving a graphics file requires 16 blocks. Safety procedures prevent the user from involuntarily erasing existing data files.

FILE MANIPULATIONS

The "reading" and "writing" options allow the user to read digital and graphics files from the disk, and to write digital and graphics files on another disk. The writing operations also allow the user to rename the files. The "printing" option allows the user to send digital and graphics files to the printer. The program of graphics file printing is specific to the ImageWriter printer and compatible with serial and superserial interface printer cards.

The "chaining" option enables the user to append two or more digital files sequentially, and to combine two or more graphics files into a new digital or graphics file. This

Figure 2. Examples of different acquisition modes.

Figure 3. Digital and graphics printings of the same set of data.

option enables the user to suspend and to restart the acquisition ad lib, and to gather the data acquired through different work sessions into a unique digital or graphics file a posteriori.

The "removing" option enables the user to delete the digital or graphics files permanently.

At the end of the "writing," "chaining," and "removing" options, the data disk is automatically "crunched." This operation analyzes how the unused space is distributed on the disk, and moves the files on the disk so that all unused blocks are combined at the end of the disk. Thus, the "crunching" process maximizes the unused space on the disk.

UTILITIES

The "formatting" option enables the user to format a data disk. A newly formatted data disk is automatically called "BLANK:." It can be given an appropriate name by means of the "renaming" option.

The "listing" option allows the user to send the directory of the data disk to either the console or the printer. All files and unused areas are listed, along with their block length, last modification date, the starting block address, and the filetype (.DIGIT or .GRAF).

Finally, the "date" option allows the user to store the current date. This date will be associated with any file

saved during the current session; it will be the date displayed for these files when the directory is listed.

DISCUSSION

The advantages and disadvantages of each system (optical and electronic) will be discussed separately.

Compared with other systems, the optical system is quite inexpensive. In addition to the computer and video configurations, it requires only a half-silvered mirror or some other analogous optical interface. Since the video-computer interface is exclusively optical, there is no problem of synchronization between the computer and the video components of the system. Consequently, the system is not only completely compatible with the different available video standards, but can also be used with printed material from other systems of image production. Compared with videographic computers, in which the complete video image is digitized frame by frame, each digital and graphics file of our system consists only of the relevant points of an image and can include several frames. Thus, memory costs are relatively low. The size of a graphics file remains constant (16 blocks, i.e., 8K). The size of a digital file depends on the number of stored records (e.g., a digital file of 1000 records requires 24 blocks, 12K). As for software, the system can be used without knowledge of the Apple Pascal language (1984b) or operating system (1984a). The program, written on a single start-up disk, can perform the following operations: formatting, renaming, and "crunching" of data disks; collecting, reading, writing, printing, dating, listing, removing, and chaining data files. Moreover, since the program was written in Apple Pascal (based on UCSD Pascal), it is relatively hardware-independent and may be easily modified and transferred to other machines and processors.

The electronic system has the same basic advantages as the optical one: low memory costs associated with selective digitization and no requirement of any knowledge of Apple Pascal. It is also independent of the video standards (SECAM, PAL, NTSC: 4.43 MHz; NTSC: 3.58 MHz). It differs from the optical system in two

respects. On the one hand, construction of the card is required, which may be more costly in terms of time and money. On the other hand, it is more precise than the optical device.

Whichever system one chooses will allow the user to collect and store digital and graphics information. The digital information contains only the spatial (two-dimensional coordinates) and the temporal values associated with points. Any further data analysis, which may include, for example, computations of angles, distances, surfaces, speeds, etc., will require specific application programs. Our pointing system has already been used successfully to investigate several phenomena (e.g., infants' head rotations during place-learning tasks, premature infants' umbilical displacement inside an incubator, infants' eye movements in visual pursuit tasks). It is potentially usable in many other areas. It is our hope that others will test, modify, and complete this program to suit their own research interests.

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APPENDIX A
Schematic Diagram of the Interface Card

APPENDIX B List of the Components and the Component Layout

LINEAR CIRCUITS:

1: LM318	HIGH-PERFORMANCE OPERATIONAL AMPLIFIER
2: 74LS74	DUAL D-TYPE POSITIVE-EDGE-TRIGGERED FLIP-FLOP
3: 74LS123	MONOSTABLE VIBRATOR
4: 74LS123	MONOSTABLE VIBRATOR
5: 74LS74	DUAL D-TYPE POSITIVE-EDGE-TRIGGERED FLIP-FLOP
6: 74LS00	QUADRUPLE 2-INPUT POSITIVE-NAND GATE
7: 74LS00	QUADRUPLE 2-INPUT POSITIVE-NAND GATE
8: 74LS193	SYNCHRONOUS 4-BIT UP/DOWN COUNTER
9: 74LS193	SYNCHRONOUS 4-BIT UP/DOWN COUNTER
10: 74LS193	SYNCHRONOUS 4-BIT UP/DOWN COUNTER
11: 6522	VERSATILE INTERFACE ADAPTATOR

POTENTIOMETERS:

50 K 4

TRANSISTORS:

2N3906 1 PNP
2N3904 1 NPN

DIODES:

1N4148 3 D1, D2, D3

RESISTORS:

75 Ω 3 R1, R4, R10
220 Ω 1 R5
270 Ω 1 R9
1 K 1 R6
1.5 K 1 R11
2.2 K 2 R2, R3
5.1 K 1 R8
22 K 1 R7
330 pF 1 C2
1.5 nF 1 C3
0.68 nF 2 C4, C5
0.22 μ F 1 C1
100 nF 1

CAPACITORS:

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