A method for analyzing the motion of an object on a VTR screen with an Apple II computer

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To detect position on a video tape recorder (VTR) monitor screen, two different types of apparatus were developed. One was a light pen, and the other was an instrument similar to an X-Y tracker. These were designed to work with the Apple II computer. Their circuit diagrams are presented.

Recently, many researchers have wished to analyze motion, such as hand movements during a reaching task. In such a case, motion is recorded on a video tape recorder (VTR). To analyze this motion, an apparatus such as the NAC SPORTIAS or the SONY MAW-5000 generally is used, both of which are similar to an X-Y position detector. However, they are very expensive.

In this article, two types of apparatus for detecting position on a VTR screen are introduced; both types are controlled by an Apple II microcomputer. The first apparatus is used to detect the position of an object on the VTR screen by using a light pen. The second is one type of X-Y position detector.

POSITION DETECTION BY LIGHT PEN

Description of the System

A TV screen is scanned from the top left corner to the bottom right corner of a frame in the manner shown in Figure 1. One frame consists of two fields. The number of scanning lines per field is $525/2$ (NTSC TV standard). Therefore, it is natural for the user to identify position on a TV screen in two dimensions based on the horizontal and vertical directions—X-axis and Y-axis, respectively.

For the NTSC standard, the starting point of scanning is the top left corner of a field, so it is convenient to make the origin of the rectangular coordinate axes at the

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Figure 1. The screen of the TV (1 – n: scanning line).

top left corner. The basic unit in the vertical direction is taken as one scanning line. The unit used in the horizontal direction is arbitrary, but the resolution of the screen in the horizontal direction must be nearly the same as that in the vertical direction. In this equipment, a horizontal line is divided into 350 points— $525/2$ (the number of scanning lines per field) multiplied by $4/3$ (the aspect ratio of a TV screen). However, a TV set also has a flyback time, or blanking period, and therefore the effective range of a scan for one frame in the horizontal direction is 85%: $525(4/3)(0.85)$, or 297 points. For the vertical direction for one field, the effective range of lines is 95%: $(525/2)(0.95)$, or 249 lines.

Principle

A TV screen is lit by a scanning electron beam striking phosphors on the screen. Therefore, by using a phototransistor, which is attached to the TV frame, one easily can detect the bright scanning light signal. The vertical position of the frame is obtained by counting the number of scan lines from the beginning of a field to the vertical point of interest. For the horizontal scan, the position is obtained by counting the scan time or pulses from the starting point of a particular horizontal

line to any point on that horizontal line. A block diagram of the apparatus is shown in Figure 2.

Horizontal and vertical synchronizing pulses are separated from the video signal by the synchronizing signal separator. The starting point of a field for both the horizontal and the vertical directions is the upper left-hand corner of the TV screen, as shown in Figure 1. The vertical spacing counter is started by the vertical synchronizing signal pulse. This counter counts the horizontal synchronizing pulses, each of which indicates the start of a new horizontal scan line.

The horizontal spacing counter is started by the horizontal synchronizing pulse, and counts the output of the horizontal pulse generator, which generates 297 pulses for one horizontal scan line. Therefore, vertical and horizontal counters indicate where the bright scanning point is located at any moment. At the same time, the video signal is sent to the TV monitor to generate a picture.

Since the scanning point is the brightest point on the TV screen, the light pen sensitivity is adjusted to detect only the scanning point and to ignore the background decaying phosphor intensity. When the light pen is pointed at a particular point on the TV screen, the scanning point is detected and the horizontal and vertical position counters are then read by the computer. After the counters have been read, they are reloaded with the maximum count and are restarted by horizontal and vertical synchronizing pulses.

Description of the Circuit

Figure 3 shows a schematic of this instrument. Q1 is a buffer used to isolate this circuit from the TV circuitry. Q2 is used to separate the horizontal and vertical synchronizing pulses from the video signal. These synchronizing pulses are converted to a TTL level by Q3 and then are buffered by U2/2, and the vertical synchronizing pulses are separated from the horizontal synchronizing pulses by an integrator circuit—R11 and C5. They are then buffered by U2/3 and are used as a start signal for the vertical line counter of the 8253 programmable timer and also as a reset for the U6/1 D flip-flop, which is used as a gate signal for U1/2 to enable or disable the counting of horizontal synchronizing pulses. The hori-

zontal synchronizing pulses, buffered by U1/1, control the oscillation circuit—U2/1, R7, R8, and C3. This oscillator does not work during the blanking period—the time between fields. There are 350 oscillator pulses for one horizontal scan line, so C3 is adjusted for 350 pulses. The output of the oscillator is buffered by U1/2 and is gated on and off by U6/1, as mentioned above.

The Intel 8253 programmable interval timer IC is used to count the horizontal oscillator output and vertical synchronizing pulses. The 8253 has three independent 16-bit counters, and it is easy to select the counting mode of each. In this equipment, counter 0 for the horizontal oscillator pulses and counter 1 for the vertical synchronizing pulses are used in mode 0. These counters are started by horizontal and vertical synchronizing pulses—gate 0 and gate 1 inputs, respectively. Each counter is initially loaded with the maximum possible count. Then, with every horizontal oscillator or vertical synchronizing clock pulse, the counters count down one increment. The output of the counters at any time is used to identify position on the TV screen. The software retrieves the lower byte from each counter first, and then the upper byte. After the counters have been read, they are reloaded with the maximum count and restarted by horizontal and vertical synchronizing pulses.

The light pen used is constructed from the case of a Magic Marker pen. R12, PT1, Q14, and R15 are inside the case, and SW1 is mounted on the surface of the case. The light pen is connected to the rest of the circuitry through a short shielded cable.

The output of the phototransistor, PT1, is a very low impedance when a large amount of light strikes its surface and a very high impedance when no light strikes it. In the intense-light condition, the voltage at the emitter of Q4 is small. In the no-light condition, the voltage is about 11 V. The comparator U5 reference voltage is adjusted using R16. Because, in the intense-light condition, the voltage at the negative input of the comparator is very small, the comparator is turned on. Q5 is also turned on in this condition, and C7 is charged to about 5 V (the charging voltage is limited by the Zener diode VZ1). This TTL level voltage is buffered by U2/4 and U1/3 and clocks the D flip-flop U6/1.

Figure 2. Light pen position detector block diagram.

Figure 3. Light pen position detector circuit. Note—All resistance values are in units of ohms; all capacitance values are in units of microfarads.

The U6/1 Q output gates U1/2 and clocks the U6/2 D flip-flop. The horizontal clock pulses to the horizontal portion counter must be inhibited after the light pen detects the scanning bright spot on the TV, because the computer response time is slower than the horizontal pulse rate. If the pulses were not inhibited, a larger count than the actual horizontal position count would result. The vertical position counter input pulses (horizontal synchronizing pulses) are not inhibited after a light pen signal has been detected because the Apple II response time is fast enough to read the counter before any further pulses reach it.

The Q output of U6/2 is used as an acknowledge flag for the Apple II, indicating that the light pen has detected the scanning bright spot on the TV screen. The computer then reads the counter position data. The acknowledge flag is reset every time the computer addresses the circuitry. SW1 is a manual switch mounted on the light pen; it sends data to the computer only when the switch is pressed. When the switch is pressed and the light pen has detected the scanning spot, data line D is low. The software uses counter data on data lines D0-D7 only when D0 is low. This allows the user to conserve the memory allocated for storing counter position data. D0-D7, A0-A3, DEVSEL, R/W, and Φ 0 are used for interfacing to the Apple II.

One problem with this circuit is in the photodetection portion. The circuit cannot distinguish between ambient room light and TV-screen light. Therefore, R16 must be adjusted so that the circuit can detect the screen light but not room light. This adjustment can be done adequately. In addition, the user can reduce the room light or provide some sort of hood for the TV screen. A more sophisticated circuit can be incorporated to detect only the screen light by detecting the short pulse width of the scanning light spot (5 microsec). Generally, for laboratory use, this is unnecessary if proper light shielding and the R16 potentiometer adjustment are used.

Connection to the Apple II

The Apple II has eight I/O slots, with addresses \$C080 to \$C0FF. The apparatus described here can be used in any slot. The addresses used for programmable timer functions in any particular I/O slot are as follows: \$C0X0—counter 0; \$C0X1—counter 1; \$C0X2—counter 3; \$C0X3—mode register; and \$C0X4—data flag.

X is a hexadecimal number from 8 to F, 8 corresponds to I/O slot 0, and F corresponds to I/O slot 7. Before any timer data are set, it is necessary to initialize the 8253 timer IC, according to Intel's 8253 data sheet. (The complete software package for this apparatus is

available to the user upon request. Please contact M. Kawai at Nagoya University.)

For this instrument, the counter is configured in mode 0 and BCD count, and in 16 bits. The shortest data-acquisition period is 16 msec, one field rate. The difference between the start and stop counts is calculated in software and is available at any memory address the user specifies.

Discussion

As described earlier, it is easy to detect the position of any point on the TV monitor with this equipment. However, stability of the position is not quite sufficient. This problem is caused by sensitivity of the photo-transistor and/or the angle of the light pen tip with respect to the screen. Thus, the apparatus is more useful in identifying the positions of large parts of objects rather than in identifying those of critical parts or of low-contrast portions of a screen.

Because the light pen position detector was not useful in identifying small parts on the VTR monitor, the X-Y tracker depicted in Figure 6 was designed.

POSITION DETECTION BY X-Y TRACKER

Description of the System

The X-Y tracker is able to track all directions of motion. A white marker superimposed on the TV screen and controlled by a joystick is used to identify manually any particular position.

A rectangular coordinate system is used to identify any point on the TV screen in software. The origin (0,0) is the upper left-hand corner of the screen. (X_{max} ,0), (0, Y_{max}), and (X_{max} , Y_{max}) identify the upper right-, lower left-, and lower right-hand corners of the screen, respectively. This is shown in Figure 4c. The user sets the values of X_{max} and Y_{max} in software.

Figure 4. Horizontal sawtooth and synchronizing waveforms and X-Y tracker circuit waveforms.

Figure 5 is a block diagram of the system. The horizontal and vertical synchronizing pulses are separated from the video image signal by the synchronizing signal separator. At the same time, the video signal, with synchronizing pulses, is sent to the TV screen. The horizontal and vertical synchronizing pulses are input to horizontal and vertical sawtooth waveform generators, respectively. Figures 4a and 4b show the synchronizing pulse waveform and sawtooth waveform and their time relationship for the horizontal direction. The waveforms for the vertical direction are similar. As part of the calibration procedure, the horizontal and vertical sawtooth voltage levels must be adjusted to correspond to the appropriate set of software coordinates: For the horizontal signal, the X and X_{max} values must correspond to 0 and 5 V, respectively. Similarly, for the vertical signal, the Y and Y_{max} values must also correspond to 0 and 5 V, respectively.

The ramping portion of the sawtooth shown in Figure 4a is a shorter time interval than the horizontal synchronizing signal period due to the pulse width of horizontal synchronizing pulses. This effective sawtooth period corresponds to an effective voltage range of 5.0 V for the horizontal direction.

The joystick consists of two potentiometers—one for the horizontal direction and one for the vertical direction. The voltage at the center tap of each potentiometer is buffered and sent to an A/D converter and then to the Apple II to record X- and Y-coordinate positions commanded by the joystick. At the same time, the joystick potentiometer center-tap voltages are compared with the appropriate horizontal and vertical position sawtooths. The output of each comparator corresponds to the time from the beginning of a scan (the upper left-hand corner of the screen) to the point on the screen commanded by the joystick. Figure 4d shows the horizontal comparator output for a point P versus the time for one horizontal scan. The output of each comparator is sent to a marker generator circuit that generates a pulse waveform (shown in Figure 4e) that is inverted by a transistor inverter-driver and is sent to the TV screen to superimpose a white mark at the point commanded by the joystick.

This mark is used to follow motion on the VTR. For example, one frame of motion at a time is displayed on the screen, and the user marks a particular point of the motion with the joystick. Then the user commands the Apple II to read the marker position. The next frame of motion is then displayed, and the user marks the same part of the motion. In this manner, the user can record the motion, frame by frame, with the computer. In this case, the VTR must be equipped with a mechanical function for advancing frames one by one.

Details of the Circuit

Figure 6 shows the circuit of this apparatus. Q1 and Q2 are used to separate the horizontal synchronizing signal from the video signal. The horizontal synchroniz-

Figure 5. X-Y tracker block diagram.

Figure 6. X-Y tracker circuit.

ing pulses are buffered by Q3 and are sent to a Schmidt trigger input NAND gate, U1/1.

U2/1 is a sawtooth generator with a frequency of 15.75 kHz determined by C10 and R19. The voltage at the center tap of the horizontal direction potentiometer of the joystick, R28, is buffered by U2/2. The horizontal sawtooth voltage and the horizontal joystick potentiometer center-tap voltage are compared at U3/1. The output of U3/1 is a pulse train with a frequency of 15.75 kHz, the horizontal scan frequency. The pulse width of the output of the comparator varies with the voltage at the center tap of R28—63 microsec at 0 V, and 0 microsec at 5 V. The waveform for one horizontal scan is shown in Figure 4d. This pulse train from U3/1 is fed to a one-shot, U4/1. This one-shot generates a narrow pulse on the 0-to-5-V transition of the comparator output pulse train, except when the reset line is low. This waveform is shown in Figure 4E. The time from the beginning of a horizontal scan line to the occurrence of this pulse corresponds to the horizontal position commanded by the joystick.

The output of Q3, the horizontal and vertical synchronizing pulse waveform, is also sent to Q4 and Q5, which separate the vertical synchronizing pulses from this signal. These pulses are then sent to U1/2, U2/3, U2/4, U3/2, and U4/2, which function in the same manner for the vertical direction and for the horizontal direction, except that the sawtooth and com-

parator output frequencies are 60 Hz, instead of the 15.75 kHz for the horizontal direction. The output pulse width of the comparator U3/2 waveform varies from 0 to 16 millisecc, depending on the position of the vertical potentiometer center tap, in the same manner as for the horizontal direction described above. The time from the beginning of a frame to the occurrence of this vertical direction pulse corresponds to the vertical position commanded by the joystick.

The horizontal one-shot output, U4/1, is inverted by Q6 and sent to the TV screen to generate one light spot. The vertical one-shot output, U4/2, is used to inhibit the horizontal pulse output of U4/1. This is done so that only one marker dot appears on the TV screen. No marker is generated during vertical positioning. This marker does not interfere with the video signal of the VTR.

Since the output of this apparatus is an analog signal, an A/D converter is necessary to convert the analog X and Y voltages to digital information for the Apple II. A commercial A/D unit can be used. A simple and inexpensive alternative A/D converter circuit is shown in Figure 7. The National 0808 ADC is the heart of this circuit. Because the 0808 is an 8-bit ADC, the resolution is 1 out of 256. Only the A address line is used. The B and C address lines are grounded. U3, the LS164 shift register, and U6, U7/1, and U7/2 are used to select which datum, X or Y, is sent to the Apple II at any

Figure 7. A/D converter circuit. Note—All resistance values are in units of ohms; all capacitance values are in units of microfarads.

point in time. X and Y data are alternately sent to the Apple II. The circuit consisting of R1, D1, and C1 is required for initial power-up of the A/D circuit. If the B input of shift register U3 is left open, the output of U3 does not toggle properly to read X and Y data alternately. U2 and U8 are latches for X and Y data, respectively. U9/1 and U9/2 are address decoders. The addresses for reading X data and Y data are \$C0X0 and \$C0X1, respectively. X is a hexadecimal number from 8 to F representing slots 0 to 7 of the Apple II.

CONCLUSION

These two position detectors have a wide range of applications. They allow researchers and practitioners to analyze almost any type of motion of an object recorded by a VTR. The light pen apparatus is useful in identifying large parts of an object, whereas the X-Y tracker can identify very small or detailed portions.

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