INSTRUMENTATION & TECHNIQUES

A hardware and software interface for sensing changes in rotary position with an Apple II microcomputer

FRANK SCHIEBER

Oakland University, Rochester, Michigan

and

CHARLES W. SNYDER

University of Notre Dame, Notre Dame, Indiana

A design for an Apple II interface that senses relative rotary position and/or motion via a digital potentiometer is presented. A thorough discussion of the circuit's theory of operation and a fully commented BASIC software listing are included. Suggested applications include an infinite-turn rotary device for psychophysical methods of adjustment, the sensing of rotary translations of a steering wheel in a driving simulator, and a digital tachometer/odometer for tracking performance on stationary exercise bicycles and treadmills.

This paper presents a hardware and software interface between the Apple II microcomputer and a digital potentiometer (Hewlett-Packard Model HEDS-7500). The HEDS-7500 is an optoelectronic device that can be used to encode the relative extent, rate, and direction of rotary motion. The circuit described has been used in numerous applications in our behavioral research laboratories. Typical applications have included an infinite-turn potentiometer (i.e., no stops) with programmable level and sensitivity for method-of-adjustment procedures, a rotary position indicator for sensing translations of a steering wheel in a driving simulator, and a digital tachometer/odometer for measuring activity on a stationary exercise bicycle. All of these applications used an Apple II microcomputer to sense and log rotational changes in real time.

The HEDS-7500¹ package physically resembles a standard analog potentiometer. It consists of a small canister from which extends a short, rotatable metal shaft. The electrical interface to the device is made via four color-coded wires: two carry rotational information and two are for the power supply connection (+5 V and ground). As the shaft is rotated, the device emits a stream of TTL-compatible digital pulses on the Channel A and B outputs (see Figure 1). For every full turn of the shaft, 256 pulses are emitted. Hence, the device is capable of very fine resolution. The direction of the shaft rotation is en-

coded by the relative phase of the dual pulse train outputs. The pulses that appear on Channel A are always 90° out of phase with those that appear on Channel B. When the pulses on channel A "lead" those on Channel B, the shaft is being rotated clockwise. Conversely, Channel B leads Channel A for counterclockwise rotation. Unlike conventional analog potentiometers, the output level does not depend on the absolute rotary position of the shaft. Also, the digital potentiometer contains no stops and can be rotated successively in either direction for an infinite number of revolutions. Other desirable characteristics of the HEDS-7500 digital potentiometer include extremely low susceptibility to electrical noise, low shaft torque (0.1 oz/in., nominal), and the capability of encoding rotational speeds up to 300 rpm.

CHANNEL A LEADS B FOR CLOCKWISE ROTATION
CHANNEL B LEADS A FOR COUNTER-CLOCKWISE
PULSE FREQUENCY: DC TO 1280 HZ (300 RPM)

Figure 1. Phase-shifted output of the HEDS-7500 digital potentiometer.

Frank Schieber's mailing address is: Psychology Department, Oakland University, Rochester, MI 48063. He can be reached via electronic mail at: Frank_Schieber@UM.CC.UMICH.EDU. Charles W. Snyder's address is: Psychology Department, University of Notre Dame, Notre Dame, IN 46556.

DECODER CIRCUIT

In order to ascertain rotational direction, external circuitry is required. This circuitry decodes the phase-shifted signals that appear on Channels A and B into mutually exclusive pulse streams that follow orthogonal directions of rotation. An example of a directional decoding circuit is presented in Figure 2B. To minimize line noise, the Channel A and B outputs of the HEDS-7500 are each conditioned with a small capacitor and an inverting Schmitt trigger (i.e., the 7414 device). The inverted Channel A and B signals are then fed into dual clocked flip-flops (the 7474). Flip-flop A is wired so that its outputs reproduce the pulse stream from the HEDS-7500 only when it is rotated in clockwise fashion. Similarly, the outputs of flip-flop B pass the HEDS-7500 pulse stream only when rotation is in the counterclockwise direction.

COMPUTER INTERFACE

The decoder logic produces two streams of pulses: one generates 256 pulses per clockwise revolution and one generates a like number of pulses for each counterclockwise revolution. To measure rotational displacement, the computer control system needs to be able to count and compare the number of pulses generated for each direction of rotation. Relative position is determined by taking the difference between these counters, and the rate of rotation for a given direction is calculated by determining the change in a counter per unit time.

The Motorola MC6840 programmable counter/timer is well suited to perform these pulse-counting functions. This device contains three 16-bit registers, which can be configured to count external events, such as the transitions of the HEDS-7500 output signal. The value of these coun-

Figure 2. Complete circuit for interfacing the HEDS-7500 digital potentiometer to an Apple II micro-computer system.

ters can be ascertained at any time simply by having the computer read two memory locations that have been mapped to the upper and lower 8 bits of each counter. Figure 2A presents the complete circuit needed to interface the 6840 counter to the Apple II series of microcomputer systems. The 6840 interfaces easily with the Apple II expansion bus because it requires only one external device to mediate data transfers to and from the host microprocessor (i.e., the 8304 octal bus transceiver). All necessary signals for addressing the various control and counter registers of the 6840 are already available on the Apple II interface connectors. In addition, a moderately priced Apple peripheral card that is completely compatible with the circuit described in Figure 2A is commercially available for those who do not prefer to pursue the do-it-yourself route.²

Two of the 6840's three 16-bit counters are utilized to track the outputs of the rotation direction decoder circuit. The clockwise pulse stream is connected to the external input of the first counter (C1), whereas the counterclockwise pulse stream is connected to the external input of the second counter (C2). The third counter is not required for the HEDS-7500 interface and could be programmed to function as a real-time clock by dividing-down the Apple's 1.08-MHz system clock. Details for such advanced programming of the MC6840 can be found in the manufacturer's data reference sheets covering the device.³

PROGRAMMING THE 6840 COUNTER

The 6840 contains several control and data registers that are accessed at eight contiguous read/write memory locations. As with most Apple II peripherals, the exact address of these memory locations varies according to which expansion slot the peripheral card occupies. The starting address of the 6840 interface depicted in Figure 2A is given by the equation: $49280 + (16 \times N)$, where N is any slot number 1 through 7.

A thorough discussion of the 6840's programming requirements is beyond the scope of this report. Instead, only the commands needed to support the HEDS-7500 interface are presented. The Applesoft BASIC program in Listing 1 contains all of the code necessary to initialize the 6840's counting functions and to read the two 16-bit counters dedicated to tracking the clockwise and counterclockwise outputs of the rotation direction discriminator circuit.

The minimal requirements for programming the 6840 consist of: (1) configuration of each counter as a 16-bit external event counter, (2) initialization of the contents of each counter, and (3) enabling the external counting process. All three steps are performed in Listing 1.

Line 102 defines the number of the Apple II slot in which the interface card is to reside (SLOT = 3). If the card is placed in a different slot, this line must be modified appropriately. The addresses of the 6840 control

registers (R1 and R2) are defined in lines 115-120, whereas the counter read/write access addresses (M1/L1, M2/L2, and M3/L3) are defined by lines 160-220. The data codes required to configure the characteristics of each counter (variables C1, C2, and C3) are defined in lines 130-150. The first actual programming of the 6840 occurs in lines 300-350. These lines configure the counters. It is essential that these commands be issued in the exact order specified in this listing. The initial values of the counters, prior to enabling the counting process, are set in lines 400-430. The high-order byte of each counter must always be programmed first. Note that the counters are initialized to their maximum values (64K), rather than to zero. This is done because the 6840 registers are count-down rather than count-up devices. Finally, the external counting process is enabled by clearing the least significant bit of control register R1 as specified in line 510. With these configurations, the 6840 automatically counts and accumulates all of the clockwise and counterclockwise pulses output by the rotation direction discriminator circuit.

The final section of the program (lines 600-730) reads the counters, calculates the accumulated clockwise and counterclockwise pulses since the process was enabled, determines the scaled relative rotary position of the digital potentiometer, and continuously displays the results on the bottom of the computer monitor's screen. Once started, this section of the program is executed continuously until a Control C is entered from the Apple II keyboard. While the program is running, the operator can directly monitor the results of manipulating the HEDS-7500 digital potentiometer.

In an application program, the 6840 must first be initialized as presented in lines 102-510. If the number of clockwise and/or counterclockwise rotations could exceed 256 (as in the case of an exercise bicycle speedometer/odometer application), the counters must be reset repeatedly, as in lines 400-430, after they are read. When such a reset cycle is implemented using an interpreted BASIC program, some data pulses emitted from the digital potentiometer can be lost. In most applications, loss of data pulses during reset of the 6840 counters is of no functional consequence. However, a routine written in optimized machine language can be developed in the case of applications in which loss of data during reset cannot be tolerated. Finally, as described on line 501, the counting process can be frozen at any time by setting the HALT control bit (i.e., POKE R1, C1). Counting can be restarted again by resetting the HALT bit via the command that appears on program line 510 (i.e., POKE R1, (C1-1)).

NOTES

1. Hewlett-Packard, Optoelectronics Division, 640 Page Mill Rd., Palo Alto, CA 94304; (415)857-1501. Price is approximately \$65 via HP distributors.

2. California Computer Systems (CCS) manufactures an Apple II peripheral card that is hardware and software compatible with the 6840 programmable counter interface described in Figure 2A. The Model 7440-A programmable timer module also contains a "kludge" area large enough to accommodate the rotation direction discriminator circuit presented in Figure 2B. The manual supplied by CCS provides an excellent tutorial description of 6840 operations and programming, includ-

ing an extended discussion of an interrupt-driven real-time clock. CCS can be contacted at: 2036 Concourse Dr., San Jose, CA 95131; (408)734-5811.

3. *Technical specifications, MC6840 Programmable Timer Module (PTM) and Programmable Timer Fundamentals and Applications Manual*, Motorola Semiconductor Products, Inc., 5005 East McDowell Rd., Phoenix, AZ 85008; (602)244-7100.

Listing 1 Applesoft BASIC Program for Configuring and Reading the MC6840 Counter

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100 REM 6840/HEDS-7500 TEST PROGRAM
101 HOME
102 LET SLOT = 3: REM CARD IN SLOT#3
105 LET S = 1: REM SENSITIVITY PRESCALER (SEE LINE 724)
110 REM DECLARE 6840 DEVICE MEMORY MAP
115 REM R1=6840 REGISTER/COUNTER BASE ADDRESS
117 LET R1 = 49280 + (16 * SL): REM $C080+(SL * $10)
120 LET R2 = R1 + 1: REM 6840 REG-2 ADDR
130 LET C1 = 17: REM 6840-REG1 CONTROL WORD
140 LET C2 = 17: REM 6840-REG2 CONTROL WORD
150 LET C3 = 16: REM 6840-REG3 CONTROL WORD
160 REM 6840 COUNTER LOCATIONS
170 LET M1 = R1 + 2: REM COUNTER-1 MSB
180 LET L1 = M1 + 1: REM COUNTER-1 LSB
190 LET M2 = M1 + 2: REM COUNTER-2 MSB
200 LET L2 = M1 + 3: REM COUNTER-2 LSB
210 LET M3 = M1 + 4: REM COUNTER-3 MSB
220 LET L3 = M1 + 5: REM COUNTER-3 LSB
300 REM PROGRAM 6840
310 POKE R2,1: REM SELECT CR1
320 POKE R1,C1: REM PROG CR1 (HALT)
330 POKE R2,0: REM SELECT CR3
340 POKE R1,C3: REM PROG CR3
350 POKE R2,C2: REM PROG CR2 (PRESELECT CR1)
400 REM INITIALIZE COUNTERS TO MAXIMUM (65535)
410 POKE M1,255: POKE L1,255
420 POKE M2,255: POKE L2,255
430 POKE M3,255: POKE L3,255
500 REM ENABLE COUNTERS
501 REM NOTE: DISABLE VIA 'POKE R1,C1'
510 POKE R1,(C1 - 1)
600 REM SCAN/PRINT CURRENT COUNTER VALUES
601 REM CW=CLOCKWISE DATA COUNT
602 REM CC=COUNTER-CLOCKWISE DATA COUNT
610 LET TM = PEEK (M1):TL = PEEK (L1): REM READ CLOCKWISE DATA
620 LET CW = 65535 - ((TM * 256) + TL): REM COUNTDOWN-TO-COUNTUP
630 LET CM = PEEK (M2):CL = PEEK (L2): REM READ COUNTER-CW DATA
640 LET CC = 65535 - ((CM * 256) + CL): REM COUNTDOWN-TO-COUNTUP
700 HTAB 1: VTAB 21
710 PRINT "CW-REG      CCW-REG      RELATIVE";
720 PRINT SPC( 39);
722 HTAB 1: VTAB 22
724 PRINT CW,CC, INT ((CW - CC) / S): REM SCALE REL POSITION/DISPLAY
730 GOTO 600: REM INFINITE LOOP
800 REM
810 REM EXIT TEST PROGRAM VIA <CTRL>C ON KEYBOARD

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