SESSION XII MICROPROCESSOR USERS GROUP

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A KIM-1 microprocessor interface for aversive conditioning applications using multiple subjects

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The development of the microprocessor and its availability at low cost permits the small behavioral laboratory to conduct experiments using large numbers of subjects under various schedules without requiring a major investment in programming equipment. An interface for the KIM-1 microprocessor is described which provides the user great flexibility in conducting experiments involving aversive conditioning procedures in many subjects simultaneously.

Psychologists interested in conducting animal behavior experiments with large numbers of subjects are frequently forced to run only a few subjects at a time due to the lack of enough programming and data collection equipment. This prolongs investigations considerably and is generally inefficient. The availability of inexpensive microprocessors such as the KIM-1 presents a solution to this problem. To take advantage of technological advances, the researcher must invest time and effort in learning how to use a microprocessor; in addition, he must generally have some assistance in interfacing the microprocessor to behavioral apparatus. The purpose of this paper is to provide an example of an interface for the KIM-1 which, with the appropriate programming of the microprocessor, permits the researcher to administer almost any aversive conditioning procedure to a rather large number of subjects simultaneously. Software for this system is described elsewhere (Lawler & Murray, in press).

The interface is suited for classical aversive conditioning, signaled avoidance, and unsignaled (Sidman) avoidance procedures. The paradigm used depends on software rather than hardware. However, the hardware presented here is amenable to a variety of paradigms.

Only a representative sample from each of the portions of the full interface will be presented here, rather

than tediously repeating some sections many times. What is actually being presented in the form of a general interface is a series of modules that may be used in different combinations to obtain the interface which most closely suits the needs of the individual investigator.

OVERVIEW OF THE INTERFACE

Figure 1 presents a block diagram of the system. The interface was designed to allow the experimenter to run three subjects in each of four boxes. The subjects are referred to as experimental (E), yoked (Y), and non-shock control (C). The responses made by the subject are transduced using a standard microswitch closure and the signals are carried via cables to the first section of

Figure 1. Block diagram of the microprocessor system. See text for further explanation.

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Figure 2. Signal conditioning. The response-transducing equipment is connected directly to the normally open and normally closed inputs of the interface. The 7407 open collector drivers should be located in the animal enclosure, with the pull-up resistors located at the signal destination. A standard NAND debouncing circuit cleans up the signal, and the output of the latch is fed directly to the LED encoding circuit and through a one-shot to the KIM-1 encoding circuit.

the interface, the signal conditioning circuit. This section debounces the signal and creates signals of appropriate length for later interface sections. The appropriate signals then go either to the front-panel LED coding section or to the input coding section. The front-panel coding section provides an LED indication of the activity in the boxes. The input coding section codes the input signals for the KIM-1 input and interrupt ports. The KIM-1, using software described elsewhere (Lawler & Murray, in press), determines the appropriate behavioral paradigm. The output interface systems are for tone and shock production and may be used as the experimenter requires.

INPUT SIGNAL CONDITIONING

Many aversive conditioning paradigms require that certain events follow the occurrence or nonoccurrence of some behavior. In order for these events to occur, the occurrence or nonoccurrence of the behavior must be recognized. Figure 2 presents the portion of the interface that serves to provide the KIM-1 with input signals of the proper form. For those paradigms where responses are not of interest, this portion of the circuit is simply inactive.

The KIM-1 requires as its input a brief low logic pulse, that is, the inputs are normally held high at +5 V dc and an incoming signal is a brief drop to 0 V dc or ground. While this requirement is fairly simple, the researcher must consider the nature of the response, the transduction of that response into a TTL-compatible signal, transmission of that signal to the microprocessor, and any signal conditioning necessary to "clean up" the signal.

The interface is designed to connect directly to the normally open and normally closed contacts of any relay or microswitch where the common contact is grounded. This allows considerable freedom in the manner in which the response is transduced and, thereby, in the nature of the response itself. For example, shuttleboxes, harpress manipulanda, running wheels, etc., are all built with NO- and NC-type contacts and thus may be used easily.

As shown in Figure 2, NO and NC inputs for the interface are connected directly to the inputs of 7407s, hex buffer/drivers with open collector outputs. The 7407s, complete with +5 and 0 V dc should be located as close to the subject as practical. The +5 and 0 V dc may be run from the interface to the animal boxes using the main connection cables. These 7407s function as line drivers and are included in the interface because the cables connecting the animal boxes to the KIM-1 may well be rather long, particularly if the programming equipment is housed in a room separate from the animal room. Transmission of TTL signals over long cables can cause considerable difficulty if precautions are not taken. The output of the 7407s, as open collector inputs of a noninverting line driver, will be low if the input is grounded and will be left to float indeterminately if the input is high or +5 V dc. For this reason, they require a passive pull-up resistor tied between the output and +5. By locating the pull-up resistors on the interface board, the NO line is pulled high at the destination of the input signal rather than at its origin; this assures that the signal will be pulled to a full +5 V dc rather than the nominal TTL output voltage, thereby improving noise immunity. Long (30 ft) cables are used regularly in our laboratory with no difficulty and it is likely quite safe to use cables of considerably greater length. As cable length increases, however, concern regarding shielding increases as well; a high-quality shielded cable should be used.

Since the switch used to transduce the response is likely to be inherently noisy and since the KIM-1 treats noise as a series of responses, such noise must be eliminated.¹ Figure 2 also illustrates the use of a standard NAND debouncing latch for that purpose.² Regardless of the amount of noise on the input line, a clean, solitary signal is obtained at the output. The output of the NAND debouncing latch is then sent to the LED display circuit and fed into an NAND one-shot to produce a 2-microsec pulse for use in the remainder of the circuit. The one-shot is included so that the responses appear, to the KIM-1, as very brief pulses; if the KIM-1 finishes its interrupt service routine while the pulse is still low, another interrupt is generated for the same signal.

Table 1

Input Port	Code
B0	Box 1
B1	Box 2
B2	Box 4
B3	Control
B4	Yoked
B5	Experimental

Note—Port B on the KIM-1 is used here as an input port. Each bit (B0-B5) is encoded in such a way that more than six inputs can be generated by reading the 6-bit word generated by an animal's response.

The cost of the components shown in Figure 2, excluding the cable, is under \$1. This cost must be multiplied by the total number of subjects to be processed at one time.

RESPONSE ENCODING FOR THE KIM-1

Of the 15 available I/O ports on the KIM-1, 6 were programmed as input ports (for detecting animal responses) and 8 as output ports (4 for shocks and 4 for tones). Since there are 12 input signals in our system (from the 12 animals), these signals must be encoded for the KIM-1. Instead of representing each animal by one input port, software examines a 6-bit word to determine which animal has responded. In this manner, 64 (2^6) animals can conceivably be processed at the same time. However, in our application, software recog-

Figure 3. Response encoding for the KIM-1. All signals from the subjects, after proper conditioning, are gated so as to provide the proper pattern of pulses at the six I/O ports programmed for input. In this way, as many as 64 subjects can be processed at the same time. (In the figure above, gating is provided for only 12 subjects.) The 74123 monostable multivibrators provide the KIM-1 with 70-microsec input pulses. The E, Y, and C lines are collector OR'd and tied to the interrupt of the KIM-1.

Figure 4. Response encoding for the LED front-panel display. The input signals are gated as in Figure 3 to provide the proper pattern of LED signals on the front panel.

nizes 12 distinct patterns at the six ports representing the 12 subjects. The box numbers and group labels associated with the six I/O ports used for input are given in Table 1.

The 12 input signals, after being conditioned in the earlier circuit, are gated through a series of multiple-input NAND gates shown in Figure 3, such that when a given input line is activated, the proper pattern of pulses appears at the input port. For example, when the experimental subject in Box 1 responds, the lines at input ports B0 and B5 go low for 70 microsec, the pulse width of the 74123 monostable multivibrators.³ Should the control subject in Box 3 respond, the lines at input ports B0, B1, and B3 would go low for 70 microsec. (While the box number and group labels are useful for our application, other investigators will obviously choose labels that make sense for their applications. It is the technique for including more input signals than input ports available that is important.)

The outputs (Figure 3) of the 74123 multivibrators, representing input ports B3, B4, and B5, are collector OR'd using 7407s, and that common input is tied to the KIM-1 interrupt line. It is important to use a 3.3-kohm pull-up resistor in this connection, as the KIM-1 requires it. The common line goes low if any of the three input ports are low. This occurs whenever a subject responds and results in an interrupt request to the KIM-1. The examination sequence for the input ports then occurs. During the 70 microsec that the interrupt line is low, no other inputs can be acknowledged. However, the probability that two subjects will respond within 70 microsec of each other is extremely low.

The cost of the components shown in Figure 3 is \$4.89. Addition or subtraction of the number of gates provides either increased or decreased capacity for the number of subjects to be processed at a given time. Since the simple NAND gates are so inexpensive, such changes are considered very economical.

Figure 5. Constant-current shock source. The KIM-1 drives a relay through a 75451 peripheral driver. The relay gates on a 200-V 10-A triac that operates the shock transformer. The microprocessor is electrically isolated from the high-voltage ac by the relay; the relay is protected from current surges by the triac. Pairs of subjects (S) are currently being shocked in parallel on each transformer. Control of current is provided for each subject.

RESPONSE ENCODING FOR THE LED DISPLAY

Front-panel LED displays are provided for each of the six input ports and for the tone and shock signals. Figure 4 presents the encoding circuitry for the input port LEDs. It is almost identical to the encoding circuitry described above. This separate gating system is used such that the LEDs are operated directly from the NAND latches in Figure 2 and thus light up long enough to be seen.

The cost of the components shown in Figure 4 is \$2.64. This circuitry is adequate for handling 12 subjects.

CONSTANT-CURRENT SHOCK SOURCES

The interface is equipped with four independent constant-current shock sources with controls to adjust current. Each shock source is currently used to deliver shock to one experimental animal and its yoked control.

The circuit for a given shock source is shown in Figure 5. The output of the KIM-1 is a low-going signal whose duration is determined by the software. This signal is fed to a 75451 peripheral driver consisting of a two-input NAND gate whose output is tied to the base of an NPN transistor capable of drawing 300 mA at high voltage. (The NAND and the transistor are drawn as discrete components even though they are actually on the same chip.) The second input of the NAND is tied high. When the KIM-1 delivers the low-going signal, the output of the NAND goes high, turning on the NPN transistor. This operates the Sigma relay (65FP1A-6DC), which turns on the 200-V ac 10-A triac (ECG 5624). Finally, the triac turns on the shock transformer (Triad P-3A). The relay isolates the shock transformer from the microprocessor. The triac is used to protect the relay from the tremendous current surge which occurs when the transformer is turned on.⁴ The power transformer delivers 500 V ac at its secondary and is rated at 20 mA.

The load for the transformer secondary is the parallel-series resistance shown in the figure. The 4-mohm one-turn potentiometers provide individual current control for the two subjects shocked on each transformer. The LED is front-panel mounted and signals the onset of shock.

The shock sources comprise the most expensive portion of the interface. The components shown in Figure 5 cost \$16.10. Several subjects may be shocked from a given power transformer, but the current available is reduced because they are connected in parallel; it may vary considerably across subjects if they are connected in series. We recommend that only a small number of subjects be tied into each shock source.

Figure 6. Tone generator. An astable multivibrator determines the frequency of the tone, in this case, 1 Hz. This signal serves as one input to a peripheral driver (75451) that is enabled by the KIM-1. Volume control is provided by the 100-kohm potentiometer. A single astable is currently used to drive four peripheral drivers for four animal boxes. The LED is for front-panel display.

Figure 7. Power supplies. A very tightly regulated and protected +12 V dc and +5 V dc are provided as the outputs of the Series μ A7800 voltage regulators. The size of the bridge and fuse depend upon the load; each regulator is rated up to 1.5 A.

tone generator

COMMENT

The tone generator is an astable multivibrator using three 7404 gates. The circuit is shown in Figure 6. The frequency of the generator is determined by the size of the capacitor. Our tone is a standard 1-kHz obtained by using a 6.8-microfarad capacitor. Smaller capacitors produce higher frequencies.

The output of the astable is fed to one input of the NAND gate in another 75451. The other input is pulled down through a 1-kohm resistor and connected to the tone output port of the KIM-1. When the output port for a given box goes high, the 1-kHz square wave is gated to the base of the transistor, turning the transistor on and off at 1 kHz. The collector of the transistor is connected to the speaker and +5 V dc in series with a 100-kohm potentiometer. The potentiometer provides individual control over tone volume. The LED is front-panel mounted to signal tone onset.

The cost of the astable is under \$1. Since several drivers may be run off of the same astable, the cost of the astable is simply added to the cost of the remainder of the circuit multiplied by the number of speakers. Cost of the items is \$3.80. Cost for our system of four sets is \$13.49.

POWER SUPPLIES

The power-supply circuit is shown in Figure 7. The KIM-1 requires +5, +12, and 0 V dc within 5%. A 24-V ac transformer rated at 2 A is used with a full-wave bridge rectifier at 2 A and 50 V ac. The ripple of the dc output is reduced to well under 5% using a 2200-microfarad capacitor between the dc outputs of the rectifier. The voltage regulators are the μ A7805 and μ A7812 and are very tightly regulated and protected. Each of the regulators is capable of delivering 1.5 A. The 115-V ac line is fuse protected at 1.5 A.

The cost of the components shown in Figure 7 is \$12.97.

While the system in use in our laboratory can accommodate 12 subjects simultaneously at the cost of approximately \$100, the modular components may be assembled in any pattern to accommodate any number of subjects up to 64. The additional cost, or reduction in cost, depends on the extent of the additions or reductions in the scope of the circuit. We believe, however, that the system described here is vastly superior to commercial solid state modules in terms of cost, flexibility, and reliability.

REFERENCE

LAWLER, J. E., & MURRAY, D. M. A software program for the control of aversive conditioning schedules using the KIM-1 microprocessor. *Psychophysiology*, in press (abstract).

NOTES

1. It is also possible to use software to clean up input signals on the KIM-1. However, the hardware debouncing described here has several advantages. To have the KIM-1 do the debouncing takes up added space in RAM, space that may be critical for programming. KIM-1 debouncing also takes much longer than the hardware debouncing shown in Figure 1. Signal debouncing in software can require up to 100 msec compared to the nanoseconds required in hardware. The probability that another animal will respond during this time is high. This can lead to an erroneous reading of the input ports.

2. A 74265 package may be used for the same purpose if component density is a problem. While the cost per package is greater, four debouncers are available in one 74265; only two may be built using a single 7400/package.

3. An interrupt request is acknowledged in 6 microsec plus current instruction time. This produces a worst case of 12 microsec. Saving current status of accumulator and X and Y indexes takes an additional 17 microsecs, or 29 microsec total. The interrupt request pin must return high before the RTI instruction is encountered to avoid a second interrupt.

4. Optically coupled isolation is probably preferable to electromechanical isolation. Devices such as the TIXH801 A.C. switch use this technique in conjunction with a triac to perform the functions of the relay and triac used here.