Robots on your own time

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SUPERKIM MEETS ET-2

PART II: SENSORS

In "SUPERKIM Meets ET-2" (*Robotics Age, Fall 1980*), I described how I interfaced and programmed a SUPERKIM single board computer (SBC) to control the Lour Control ET-2 robot shell.

Without sensors, though, the SUPERKIM/ET-2 combination described in that article is not a true robot, since all of its movements are "open loop," that is, without feedback. This article describes how to interface contact sensors and sensors that require A-to-D conversion (such as infrared scanners or temperature sensors) to the SUPERKIM/ET-2. Once you interface the contact sensors furnished with ET-2, you can program avoidance behavior. This permits the SUPERKIM/ET-2 to sense when it has contacted an obstacle, and take appropriate avoidance actions. I refer the reader to the Fall 1980 article for details concerning motion control of the ET-2 by the SUPERKIM.

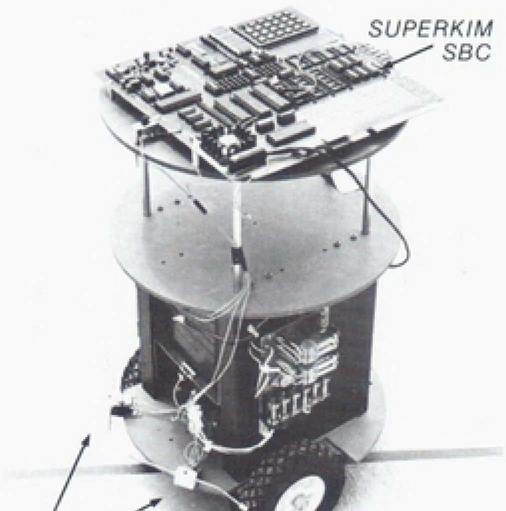


Figure 1. Contact sensors can be mounted around the base of ET-2.

Interfacing ET-2 Contact Sensors to the SUPERKIM

ET-2 provides a number of contact sensor switches that can easily be interfaced to the SUPERKIM. These contact sensors, equipped with metal "feelers," can be mounted around the base of the ET-2 to sense contact with an obstacle by means of a switch closure.

Lour Control has provided four independent contact bumper assemblies, which are designed to ring around the base of ET-2 as shown in Figure 2. Whenever a guard rod, which projects out of either side of the assembly, comes in contact with an object during ET-2's motion, it is deflected laterally, activating a built-in momentary switch. Depending on which way the switch is toggled, and on the control program in SUPERKIM, the ET-2 can then perform an avoidance manuever.

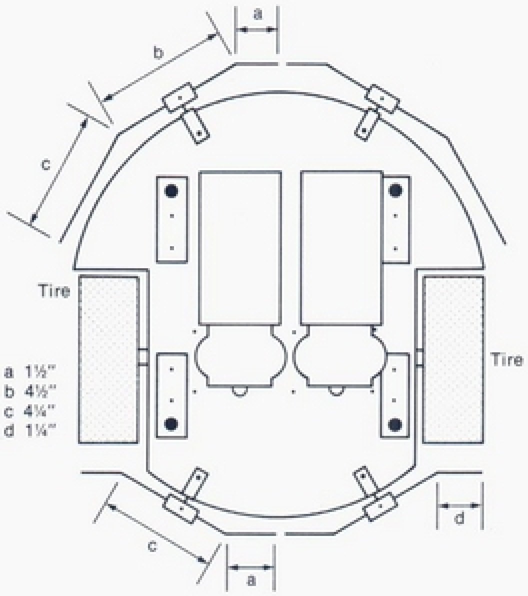


Figure 2. Location of contact switch/bumper assemblies.

Table 1

Connector Jack J2 (U11) 6530-003 I/O

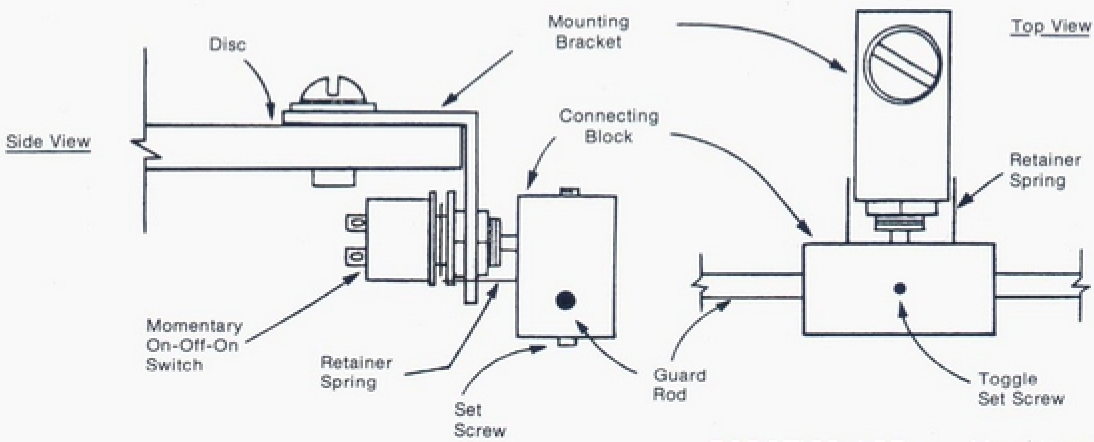
Pin 0	=	Ground
Pin 1	=	PA0
Pin 2	=	PA1
Pin 3	=	PA2
Pin 4	=	PA3
Pin 5	=	PA4
Pin 6	=	PA5
Pin 7	=	PA6
Pin 8	=	PA7

As figure 3 shows, each of the bumper switches have four basic parts—the guard rod, connecting block, switch, and mounting bracket. The guard is a 5/32 inch diameter rod that protrudes from both sides of the connecting block and acts as an extension of the switch's own toggle lever. You can easily distinguish the two bumper assemblies installed in the front section of the shell, since their guard rods are shorter than those mounted in the rear section. The switch's toggle lever and the guard rod are both attached to the connecting block by means of set screws. The switch itself is a momentary, on-off-on device that automatically returns to the center (off) position when released. A spring wire, wrapped around the switch's mounting stud, holds the connecting block in a horizontal position and aids in the resetting of the switch. The entire unit is attached to one of the four mounting holes on the tier of ET-2 by means of a corner angle mounting bracket.

We used SUPERKIM's 6522 to interface the SBC with ET-2's motor and relay controls. SUPERKIM also comes with two 6530 ROM/interface ICs, designated 002 and 003. To interface these sensors to SUPERKIM, we must first consider the operation of the I/O ports in a 6530. Each 6530 array provides 15 I/O pins. The microprocessor and operating program define whether a given pin is an input pin or output pin, determine what data are to appear on the output pins, and read the data appearing on the input pins. The I/O pins provided on 6530-002 are dedicated to interfacing with specific elements of the KIM-1 system, including the keyboard, display, TTY interface circuit, and cassette tape interface.

The I/O pins on the 6530-003 (U11) are brought out to connector jacks J2 and J3, and are available for user applications. Connector jack J2 has 8 pins constituting Port A, as shown in Table 1. Connector jack J3 has 5 pins constituting Port B, as shown in Table 2. Pin 0 on Port A is a ground line. Pins 1 through 8 on Port A and pins 1 through 5 on Port B are the programmable I/O lines. Figure 4 shows the location of the pins on the 6530-003 connectors J2 and J3 that are used as contact sensor input lines.

Figure 3. Contact sensor assembly (detail).



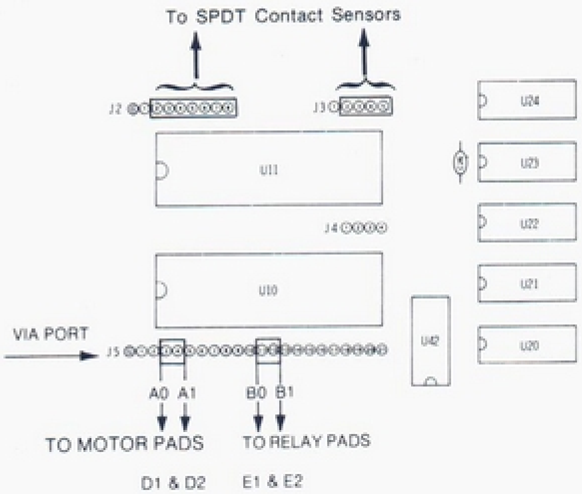


Figure 4. SUPERKIM/ET-2 contact sensor interface connections.

Each of the lines shown in Figure 4 go to one end of the desired (SPDT) contact sensor, as shown in Figure 5. Since the central pole of the switch is connected to ground, as the switch is opened and closed, the corresponding pin on jack J2 or J3 will be either an open circuit (corresponding to logic 1) or grounded (corresponding to logic 0). Read the data registers for Port A from memory location 1700H and the data registers for Port B from memory location 1702H.

You can interface the touch sensors by connecting one side of the SPDT switches mounted around the base of the ET-2 to signal ground and the other side to the appropriate pins of Port A and Port B. To understand how this connection works, consider the partial state diagram of the data register shown in Table 3.

If any of the pins PA1 through PA8 are connected to ground, then the corresponding state of the data line is set to zero, as shown in Table 3. The data byte stored in memory location 1700H—and read out by the KIM display—is the hexadecimal equivalent of the binary number represented by the states of the signals on PA1 through PA8, with PA1 being the least significant bit (LSB) and PA8 being the most significant bit (MSB). Thus, Port A alone can handle some 2^8=256 on-off contact sensor states.

Table 2

Connector Jack J3 (U11) 6530-003 I/O

Pin 1	=	PB0
Pin 2	=	PB1
Pin 3	=	PB2
Pin 4	=	PB3
Pin 5	=	PB4

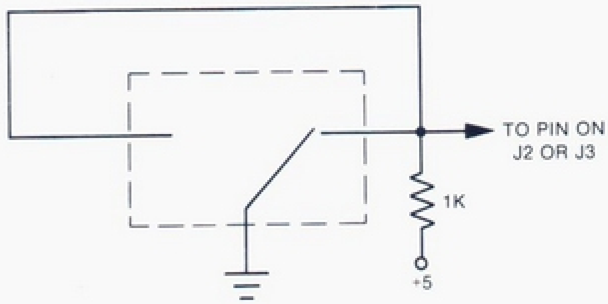


Figure 5. Contact sensor connection.

Motion Commands Based on Contact Sensor Data

The SUPERKIM can use contact sensor data to initiate a sequence of avoidance maneuvers any time the robot comes into contact with an obstacle. This behavior can be very complex, since a different avoidance maneuver routine can be triggered for every possible combination of contact sensor output. When all 8 contact sensors are mounted around the base of ET-2, the robot might use as many as 256 different avoidance maneuvers.

The principles behind this can be illustrated by considering two touch sensors on the front of ET-2, both wired to PA1 of Port A. In this case, KIM gets data byte FE if either front sensor contacts an obstacle. Table 4 gives a simple program making use of this data in a closed-loop fashion.

Execution of the program in Table 4 allows the SUPERKIM/ET-2 combination to go exploring somewhat in the manner of a billiard ball. The ET-2 moves forward in a stop-and-go fashion until one of the two forward contact sensors touch an obstacle. When this happens, the avoidance routine is called, which rotates SUPERKIM/ET-2 until the touch sensors are no longer in contact. Then the robot resumes its forward stop-and-go motion. Figure 6 shows the path of SUPERKIM/ET-2 under control of this program.

Table 3

Data Byte Equivalent of Port A Sensor Signals

Address	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	DATA BYTE
1700H	1	1	1	1	1	1	1	1	FF
	0	1	1	1	1	1	1	1	FE
	1	0	1	1	1	1	1	1	FD
	1	1	0	1	1	1	1	1	FB
1 = Open	1	1	1	0	1	1	1	1	F7
0 = Grounded (closed)	1	1	1	1	0	1	1	1	EF
	1	1	1	1	1	0	1	1	DF
	1	1	1	1	1	1	0	1	BF
	1	1	1	1	1	1	1	0	7F

As figure 6 shows, the path of ET-2 looks something like the trajectory of a billiard ball. By changing the program's delay constants at 0300H, 0311H and 0313H, you can change the angle of rotation of ET-2 during the avoidance manuever, as well as the duration of the start and stop motions.

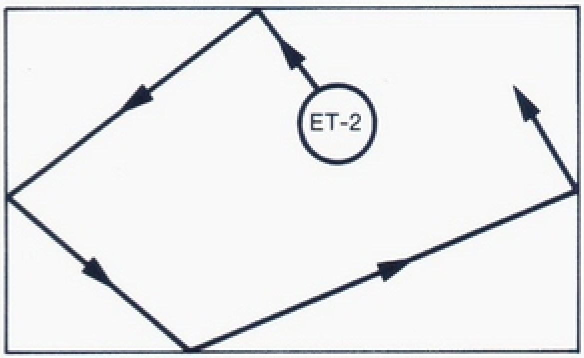


Figure 6. Path of ET-2 under control of the SUPERKIM "Billiard Ball" program.

Interfacing Analog Sensors to ET-2

Besides interfacing ET-2's contact (touch) sensors to the 6530 I/O parts you can also interface sensors that require analog to digital conversion (A/D). Sensors require A/D conversion when their output is a continuously variable signal or voltage as opposed to the 1 or 0 binary output of a touch sensor. Examples of such sensors useful in robotics are force/pressure transducers, temperature sensors, infrared sensors, or potentiometers used for shaft angle feedback in computerized servo control.

Table 4

"Billiard Ball" Program Listing

Address	Contents	Label	Operation	Comments
0200	A9 03	Loop:	LDA #$03	;Polygon Program
0202	8D 03 13		STA $1303	;Turn Relays Off
0205	A9 00		LDA #$00	
0207	8D 02 13		STA $1302	;Both Motors On
020A	20 00 03		JSR LDELAY	;Wait
020D	A9 03		LDA #$ 03	
020F	8D 02 13		STA $1302	;Both Motors Off
0212	20 00 03		JSR LDELAY	;Wait
0215	AD 00 17		LDA $1700	;Check Contact Sensor
0218	49 FE		EOR	;Compare with FE
021A	FO 03		BEQ (Z=1)	;Avoidance if FE
021D	4C 00 20		JMP LOOP	;Keep On Going
0220	A9 01	Avoidance:	LDA #$01	
0222	8D 03 13		STA $1303	;Right Relay On
0225	A9 00		LDA#$00	
0227	8D 02 13		STA $1302	;Both Motors On
023A	20 00 03		JSR LDELAY	;Wait
023D	A9 03		LDA #$03	
023F	8D 03 13		STA $1303	;Turn Relays Off
0242	A9 03		LDA #$03	
0244	8D 02 13		STA $1302	;Both Motors Off
0247	20 00 03		JSR LDELAY	;Wait
024A	60		RTS	;Loop:
0300	A0 01	LDELAY:	LDY #$01	;Set Default Count
0302	8C 20 03	LOOP1:	STY COUNT	;Save It
0305	20 10 03		JSR SDELAY	;Call Short Delay
0308	AC 20 03		LDY COUNT	;Get Count
030B	88		DEY	;Count Down 1
030C	D0 F4		BNE LOOP1	;Continue Til Zero
030E	60		RTS	;Return
0310	A2 FF	SDELAY:	LDX #$FF	;Outer Constant
0312	A0 FF	LOOP2:	LDY #$FF	;Inner Constant
0314	88	LOOP3:	DEY	;Inner Countdown
0315	D0 FD		BNE LOOP3	;Loop Until Zero
0317	CA		DEX	;Outer Countdown
0318	D0 F8		BNE LOOP2	;Loop Until Zero
031A	60		RTS	;Return From Subroutine
0320	00		COUNT: (Long	Delay Count Hold Location)
			END	

An LSI circuit, the ADC0817, is the primary IC in a 16 channel 8 bit A/D converter (ADC) system, which you can attach to the bus of the SUPERKIM 6502.* This ADC chip provides a relatively fast (100 microsecond) conversion time. Once the conversion has begun, the CPU can work on other tasks until the digital result is available.

The ADC0817 appears to the program as a block of memory starting at a base address, BASE, and extending through 16 locations to BASE + 15. (The actual circuit described occupies 4000 locations because of incomplete decoding which you can remedy if desired.) A conversion of a selected channel, say channel X, is started by writing to BASE + X. The 8 bit conversion result may then by read from any location in the block (eg. BASE) any time after the 100μs conversion time has elapsed. If you need multiple A/D conversions at the maximum speed, you can keep the 6502 busy with "housekeeping" during the conversion delay time. The system uses just five integrated circuits. The design, shown in Figure 7, occupies six square inches on the SUPERKIM prototype area, and draws only 60 mA of current from the 5 Volt DC power supply.

Operation of the circuit is simple because the ADC0817 performs all analog switching and A/D functions. The microprocessor R/W and ϕ1 lines, along with an inverted board select signal, are combined in two NOR gates, which 1) latch channel select bits A3-A0 and start A/D conversion during ϕ1 write cycles, and 2) enable the tri-state data bus drivers during ϕ1 read cycles.

You may want to take advantage of the SUPERKIM's interrupt circuitry to allow your program to go on to other tasks after starting the A/D conversion. The ADC0817 produces an end of conversion (EOC) signal when the most recent conversion has been completed. You can connect the EOC to a processor interrupt line (such as pin

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*Both Texas Instruments and National Semiconductor produce the ADC0817.

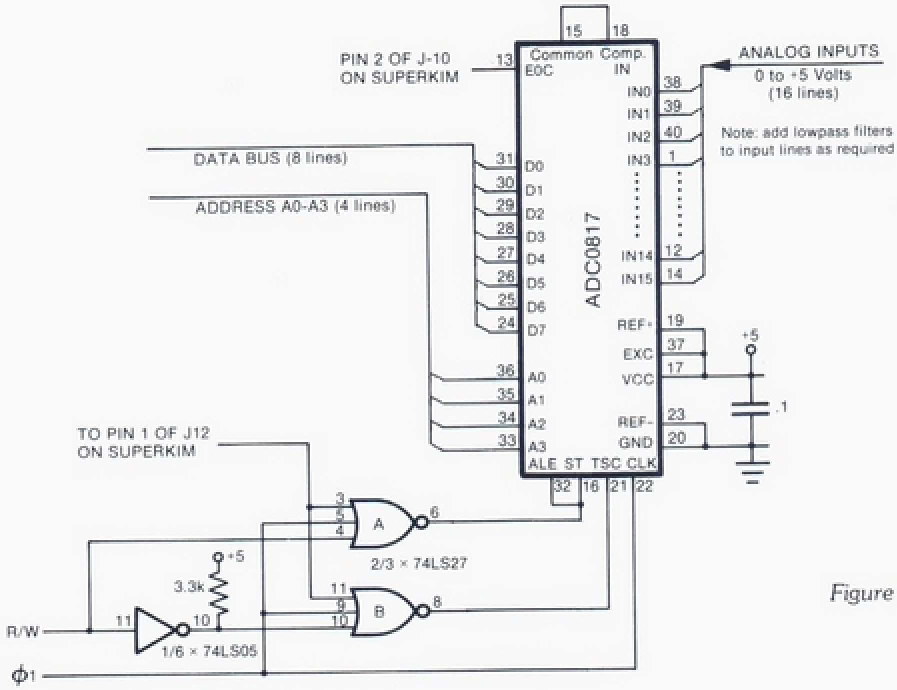

Figure 7. 16 channel analog-to-digital converter system.

2 of connecter J-10) through one of the 74LS05 open collector inverters. These interrupts can only be cleared by starting another A/D conversion. To use the interrupt feature, you must write additional software to initialize the processor interrupt and to "handle" the interrupt when EOC occurs.

Wire-wrap construction is suitable for the circuit—and component layout is not critical. It is good practice, however, to orient the analog input area away from digital circuits. The ADC circuit has two limitations: 1) analog input voltages must be between 0 and +5 Volts, and 2) the signals being converted should not change appreciably during the 100 μs conversion period.

Table 5 depicts subroutine MCAD for multi-channel A-to-D conversion without using interrupts, along with an example of a calling routine for MCAD.

The program which calls the A-to-D conversion subroutine must initialize both the channel selection and storage-defining parameters before the JSR instruction is executed. In the program given, the channel selection information is contained in an index register for ease of use in starting a conversion.

Table 5

A-to-D Conversion Routine

```
0200           BASE   *      $B000   ;BASE ADDRESS OF ADC0817
0200           STORE  *      $9000   ;START OF 16 BYTE STORAGE
                                            AREA
0200 9D 00 B0  MCAD   STAX   BASE    ;START CONVERSION ON
                                            CHANNEL X
0203 A0 0E            LDYIM  $0E     ;DELAY FOR CONVERSION
0205 88        DY     DEY            ;MINIMUM VALUE = $0E
0206 D0 FD            BNE    DY
0208 AD 00 80         LDA    BASE    ;GET CONVERTED DATA
020B 9D 00 90         STAX   STORE   ;STORE DATA
020E CA               DEX
020F 10 EF            BPL    MCAD    ;DO NEXT CHANNEL
0211 60               RTS            ;FINISHED
```

Example Calling Routine for MCAS

```
0212 A2 0F     MCMAIN LDXIM  $0E     ;SELECT CONVERSION OF ALL
0214 20 00 02         JSR    MCAD    ;16 CHANNELS AND GO TO
                                     ;SUBROUTINE
0217 00               BRK            ;EXIT '' BE SURE TO INIT IRQ
                                     ;VECTOR''
```

Conclusions

The SUPERKIM controlled ET-2 robot is an excellent, moderately priced system to which the robotics experimenter can easily add more sensors and other equipment.

The contact sensors provided with the ET-2 leave something to be desired in that they do not make contact with overhanging obstacles such as tables and chairs. They do work adequately with vertical walls, and can be used to demonstrate obstacle avoidance behaviour in a suitably prepared environment. ®

References

[1] D. F. McAllister, "SUPERKIM Meets ET-2," *Robotics Age*, Fall 1980.

[2] "Instructions for SUPERKIM," Lamar Instruments, 2107 Artesia Blvd., Redondo Beach, Calif. 90278.

[3] "ET-2 Assembly Manual," Lour Control, 1822 Largo Crt., Schaumberger, Illinois 60194.