CHAPTER 3

LOUISIANA STATE UNIVERSITY MEDICAL CENTER

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Multi-Channel Force Sensing Resistor Switch

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INTRODUCTION

Switches are often used by handicapped children to operate communication and educational aids, computers, environmental controls and mobility aids. Severe motor impaired students often have difficulty controlling the amount of force that is applied to such a switch. The result is a "wearing down" of the sensitivity of the switch. Other students, however, may not elicit an adequate amount of pressure to activate the switch. This points out the need for a pressure sensing switch that can be adjusted to control the threshold force necessary to activate the switch. In this study, we have used a commercially available force sensing resistor (FSR) to build such a switch. An additional requirement was that the device would support three separate switches with each independently controlling a single device.

SUMMARY OF IMPACT

The device shown in Figure 1 has been in use for the past year at the Caddo School for Exceptional Children. A variety of children have used the device successfully. The device has been incorporated into many frequent routines involving play and learning activities. Additionally, the device has demonstrated a wide range of applications in addition to the initial applications it was designed for. Some minor enhancements ***and*** modifications have been indicated that are being incorporated into the device.

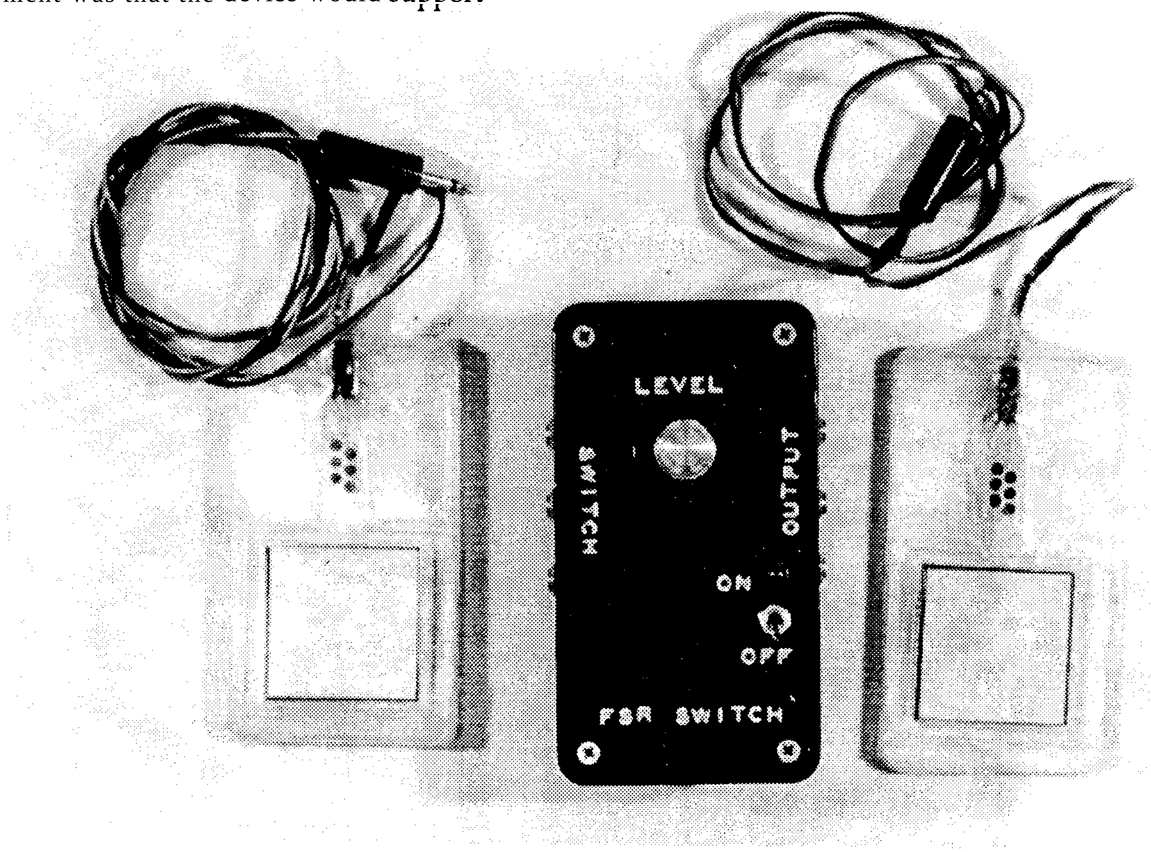

Fig. 7. Picture of device showing the enclosure containing the circuitry (center) and FSR sensor assemblies.

TECHNICAL DESCRIPTION

Force Sensing Resistor

The force sensing resistor (FSR) is a polymer thick film device that has been developed for several applications, one being human touch control. Although the FSR superficially resembles a membrane switch, the FSR differs from a conventional switch in that it exhibits a decreasing resistance with increasing force applied normally to the surface of the device. The typical FSR construct consists of two sheets of a polymer film (GE's ULTEM) with a conducting pattern on one sheet and a proprietary conductive polymer on the other sheet. The FSR is commercially available (Interlink Electronics) in a variety of sizes (cross sectional area and geometry) and thickness (0.05mm to 0.8mm). The force range of a typical FSR is from about 10g to as much as 20g and a resistance > 1 Megohm with no force applied decreasing to 1 Kilohm or less with maximum load. However, the FSR is not a load cell or a strain gauge and is not suited for exact force measurement. Additionally, the FSR exhibits an approximately log-log relationship between force and resistance, which can be represented by the equation

$$R = K \times F^{-a} \tag{1}$$

where R is the resistance in ohms, F is the force in grams, K is some constant, and a is some fractional power. This becomes important in the circuit designs, which will be discussed later. From data collected on a small sample of FSR's the following values were obtained

$$R = 10^{6} \times F^{-0.8} \tag{2}$$

Circuit Design

One such device designed around the FSR is shown in Figure 1. The FSR's are shown mounted on Plexiglass plates with the complete construct having a thickness of 6 to 7mm. The device shown in Figure 1 was designed to provide 1 to 3 independent channels of operation with the possibility of an additional fourth channel. The circuitry for this is schematically diagrammed in Figure 2. As is shown in Figure 2, a quad comparator (LM339) is used and a single reference circuit provides the reference level for each channel. The output voltage for each comparator is given by

$$V_0 = \begin{cases} 0 & V^{+} \le V_r \\ V^{+} - V_r & V^{+} > V_r \end{cases} \tag{3}$$

where V_0 is the output voltage, V^{+} is the voltage

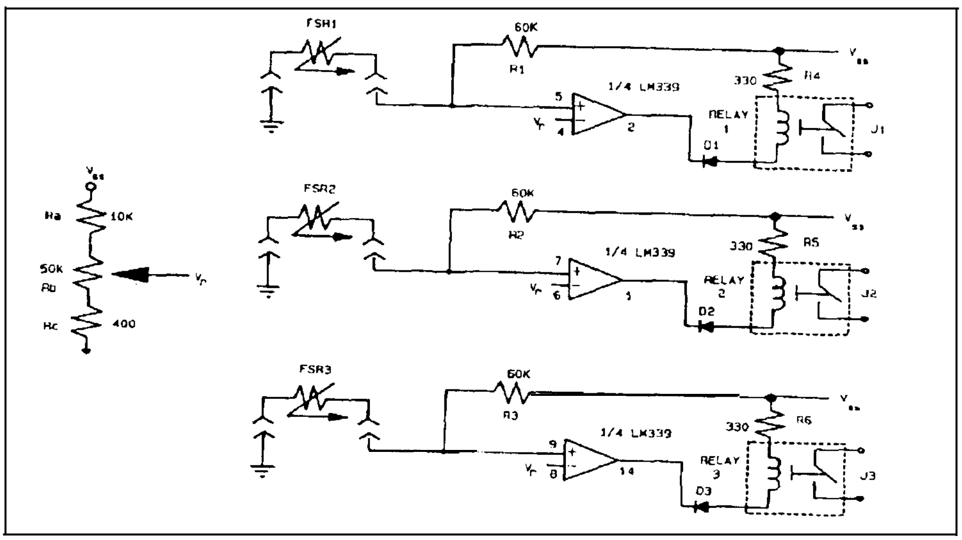

Fig. 2. Schematic ***of circuitry showing all three channels and reference circuit.***

drop across the FSR, and V_r is the voltage drop across the slider of a variable resistor R_b (shown in Figure 2). As force is applied to the FSR, its resistance decreases until V^+ is less than or equal to V_r. When this occurs, the output of the comparator is low and the relay is activated turning on the device connected to it. When the force is decreased, the voltage output of the comparator is again high and the relay is deactivated turning off the device connected to it. The connectors shown in Figure 2 are 3.5mm phono jacks. The two voltages V^+ and V_r are given by the following equations

$$V_r = (R_c + R_{b2}) \times \frac{V_{ss}}{(R_a + R_b + R_c)} \quad (4)$$

$$V^+ = R' \times \frac{V_{ss}}{(R + R')} \quad (5)$$

where R_{b2} is the resistance between the slider and the connection to R,, R_b is the maximum value of the variable resistor, R' is the resistance of the FSR, R is the resistance of the other resistor (R_1, R_2, or R_s), and V_{ss} is the supply voltage. For optimal operation at the end points, the following relations should hold true

$$V_r \min > V^+ \min \quad (6)$$

$$V_r \max > V^+ \max \quad (7)$$

These relations being true would allow for activation at both the highest and lowest reference settings. It can be shown from Equations 4 through 7 that for selected values of R, R,, and R_b, R_c can be expressed as

$$R' \min \frac{(R_a + R_b)}{R} < R_c < R' \max (R_a/R) - R_b \quad (8)$$

However, the FSR when maximum force is applied, should have less than 1 mA/cm2 of the applied force, therefore

$$i_{max} = (1 \text{ ma/cm}^2) \times S \quad (9)$$

and

$$R \geq V_{ss}/i_{max} - R'_{min} \quad (10)$$

where S is the cross-sectional area of applied force in cm^2. It should be noted the Equation 10 only determines the lower bound for R. By careful inspection of Equation 8, it also can be seen that R should be large. Also, by inspection of Figure 2 and Equations 4 and 5, it is evident that if

$$R = R_a + R_b \quad (11)$$

$$R_c > R'_{min} \quad (12)$$

then Equations 6 and 7 are satisfied. If the maximum force applied to the FSR is to be less than the maximum force of 20kg and the best sensitivity was desired R_c would be the only value to change. Letting R'_{low} be the resistance corresponding to the force R_c becomes

$$R_c \geq R'_{low} \quad (13)$$

where $R'_{low} > R'_{min}$. For the circuit in Figure 2, R was selected to be 60 kohms and R'_{min} was determined to be approximately 300 ohms. Therefore, R_c was chosen to be 400 ohms with R_a = 10 kohms and R_b = 50 kohms.

Design Considerations

One of the main considerations or difficulties in the design is the inherent nonlinearity of the FSR. This can be seen by setting $V+ = V_r$ and solving for R_{b2} as a function of applied force necessary for activation. From Equations 4 and 5

$$R_{b2} = \frac{(R'(R, + R_b) - RR,)}{(R + R')} \quad (14)$$

now substituting Equation 1

$$R_{b2} = \frac{(KF^{-a}(R_a + R_b) - RR,)}{(R + KF^{-a})} \quad (15)$$

it can be seen from Equation 15 that the force, F, appears in both the numerator and denominator that along with the fractional power, a, results in a nonlinear relation. This result for the circuit shown in Figure 2 using Equation 15 and the values from Equation 2 for K and a, is illustrated in Figure 3. If a specific range of force is chosen, the equations and values can be selected to yield an optimal behavior. Since little data exist on the forces applied by handicapped children, this process of choosing a specific range could not be done at this time.

An additional consideration is the total power consumption of the circuit due to the requirement that the device was to be battery operated and portable. The LM339 has a typical supply current demand of 0.8mA DC with a supply voltage of 36V DC. With a typical 9 volt battery with 200 to 500 mA-Hrs. of capacity this would result in 250 to 625 hours of continuous operation, yet a 6 volt battery pack of 4 AA batteries would have a capacity of approximately 2100 mA-Hrs. resulting in 2625 hours of continuous operation. The present device operates on a 9 volt source, yet the enclosure is being modified to contain a 6 volt source as described above. Although the relays may draw 20 to 60 mA, this is one of such short duration that the supply current demand determines the approximate battery life.

The physical construct of the FSR as shown in Figure 1 has certain features that require consideration. The existence of and preload on one sensor that does not equally exist on another may result in problems with a single reference channel. This can be eliminated by careful construction and design of the sensor that either results in no preload or a consistent, uniform preload. The variation of one FSR behavior to another is about 15% for the worst case, yet this also can be controlled by careful sensor design and construction. The construct should provide adequate protection and physical support of the FSR, yet allowing for a thin (less than lcm) sensor with a large surface area (16cm2 or more) and sufficient durability (can be dropped from 4 feet onto a semi-hard surface without severe damage).

The cost of a typical FSR of the type shown in Figure 1 is from $1 to $2 for the standard sizes and shapes. The total cost of the device is $20 to $25 including the sensors and batteries.

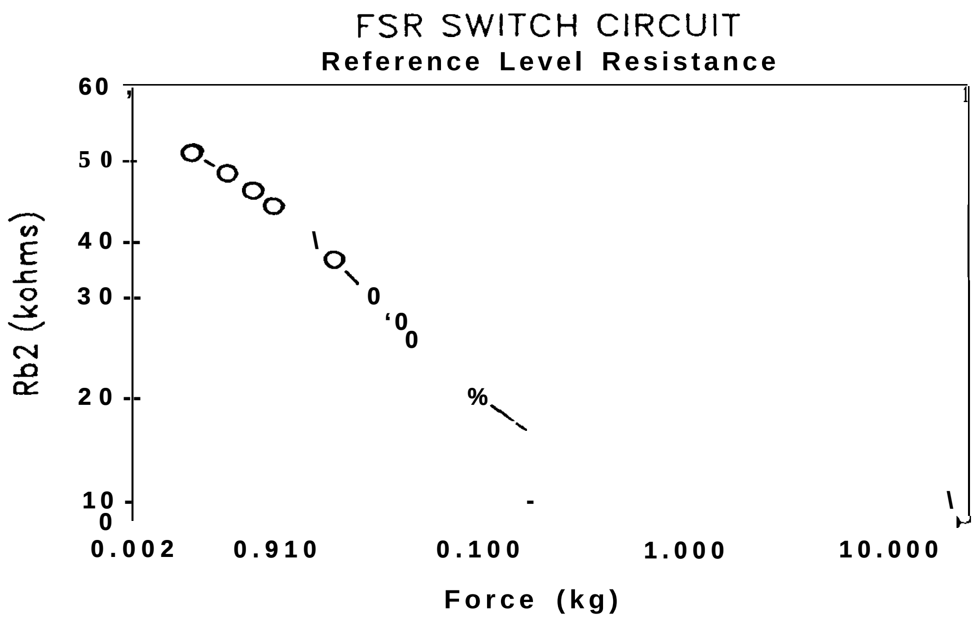

Fig. 3. Graph illustrating the effect of the non-linear behavior of the FSR. The data represents the potentiometer setting necessary for a desired force of activation.

Upper Extremity Training Device

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INTRODUCTION

Some children in wheelchairs have difficulty using crutches or a walker due to their inability to support their body weight with their arms. With proper training, these children can learn to support themselves with their arms and eventually learn to use crutches or a walker. This transition from wheelchair to crutches or a walker can be very beneficial to the child by allowing him to become more mobile and independent.

The purpose of this project was to design and build a device to measure the amount of vertical force a child applies while performing a shoulder depression motion. When the actual level of force being applied exceeds a desired level preset by the therapist, the child receives reinforcement through the activation of a toy connected to the device. The therapist can increase the desired level until the child can apply enough vertical force to support his own body weight. After this goal is reached, the child can begin training on the use of crutches or a walker.

SUMMARY OF IMPACT

Actual use of this device cannot begin at the Caddo School for Exceptional Children until the beginning of the new school year. However, discussion with the physical therapist indicates that this device will be beneficial in assisting her to teach these children to support their body weight with their arms and then eventually to use a walker or crutches.

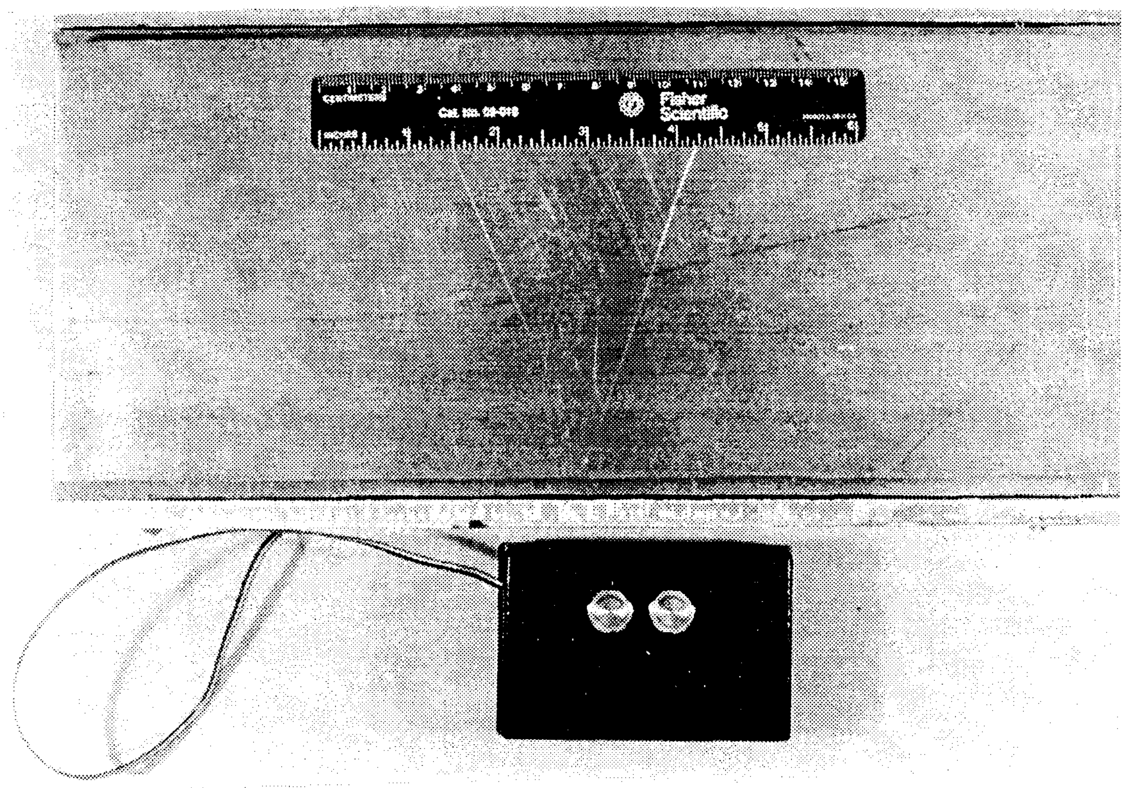

***Fig. 1. Force plate (top) and** electronics (bottom).*

TECHNICAL DESCRIPTION

The upper extremity training device consists of two force sensing plates (for the left and right sides), a control box for the therapist, and two stages of reinforcement (Fig. 1).

Each force sensing plate is constructed for 1/4" aluminum tolling plate and contains a 200 pound load cell (A. L. Design, Inc., Model ALD-W-2) as the force transducer. The output of the load cell is fed into a three op-amp amplifier circuit. Two of the three op-amps provide high input impedance into the amplifier, and the third op-amp provides differential amplification of the two signals from the load cell. Since the voltage output of the load cell is proportional to the force being applied to it, an adjustable gain on the amplifier is required in order for the amplifier to maintain adequate levels of output at low levels of input force. The gain is adjusted by choosing different resistor values for Rx. The resistors R_{x50} and R_{x100} set a gain equivalent to a 50 lb. and 100 lb. load range respectively. This adjustable gain is accomplished by replacing one of the resistors in the amplifier circuit with a potentiometer. The amplified output from the load cell is compared with the potentiometer-controlled, desired level set point using a LM339 comparator chip. When the actual level exceeds the desired level, the first stage of reinforcement is activated (Fig. 2).

The first stage of reinforcement is simply a LED for each side. When the actual level from the load cell exceeds the desired level set point, the comparator output goes to a "low" state and the LED lights up. The comparator outputs from each side are also fed into an OR gate (7432). When the actual load level exceeds the desired level on both sides, then the second stage of reinforcement occurs. The second stage of reinforcement is a relay that operates the child's toy. Once activated, the toy continues to operate until the actual load levels fall below the desired level.

The material and electronic components for this project cost approximately $25. The major expense was the load cells, which cost $280 each.

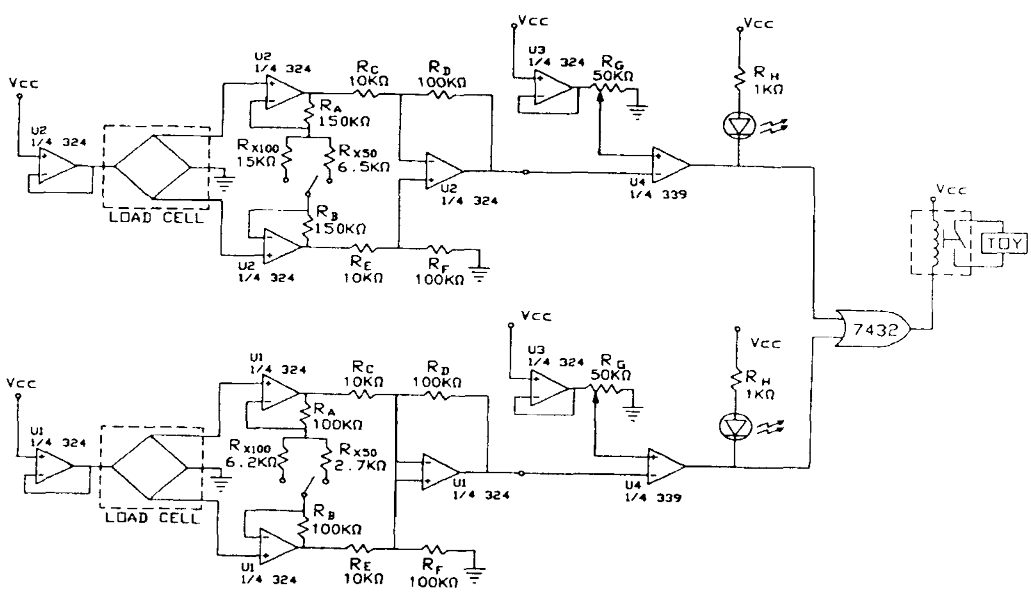

Fig. 2. ***Schematic diagram of circuitry showing*** *both left* ***and right sides and reinforcements.***

Battery Operated Proximity Switch

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INTRODUCTION

During the last decade, microcomputers have become more readily available for the disabled population, and this has provided a more convenient means of communication and an increased level of independence for them. However, due to severe motor deficiency, many children at the Caddo School for Exceptional Children (CSEC) cannot directly access computers and other electronic augmentative devices. For such students, there is a definite need for an economical, durable switch that a child can operate easily and that can act as an interface between the child and the computer or any other electronic device. In some cases, the switch is required to be low force or even zero force activated. Small size and easy handling with little or no risk of damage or injury to the child is also required. Additional requirements are that the device must be small, portable, and battery powered. No commercial device has been found that meets these requirements. Therefore, such a device has been developed.

SUMMARY OF IMPACT

This device has been used by several physically disabled students. Previously, one student with cerebral palsy communicated through a computer via a microswitch that was activated by her head movement. This switch often needed repair due to the constant impact from the head movement. This microswitch was replaced by the proximity switch (non-contacting capacitive switch), and it has performed efficiently without any breakdown. Other students with severe visual and physical deficits have also used the device allowing the child easier access. Some advantages of this device are 1) the probe is connected by cable to the electronics allowing for the activation area to be custom designed and changeable to meet a specific need, 2) the sensitivity of the device is adjustable, and 3) the small size, portability, and DC battery power allows the device to be utilized in a variety of locations.

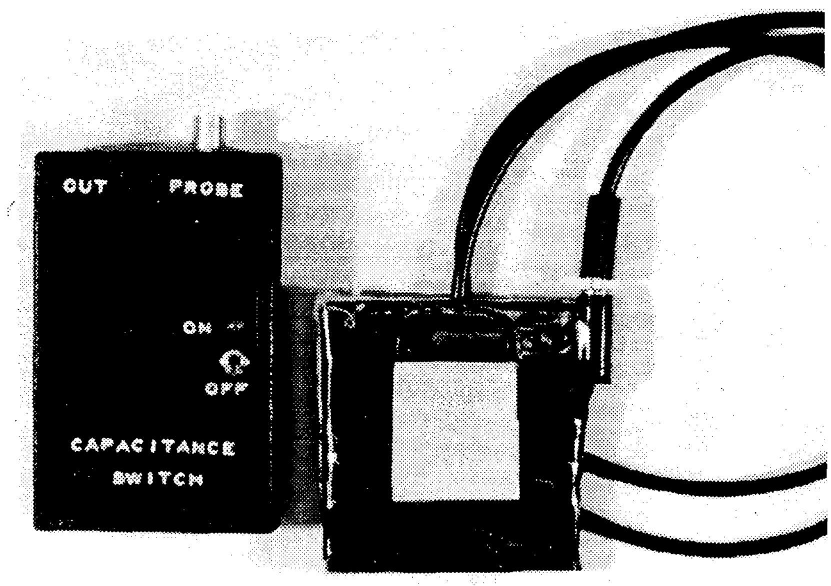

Fig. 1. Battery operated proximity switch showing a probe, connecting cable and circuitry (capacitance switch)

TECHNICAL DESCRIPTION

Figure 1 shows the physical device that consists of an insulated metal plate (probe), connecting cable, and the circuitry. The method of operation of the device is based on the capacitive coupling between the probe and a part of the child's body such as the hand, foot, head, or other part. The enclosure shown in Figure 1 contains the circuitry, battery, and connectors required by the device. Figure 2 is a schematic diagram of the circuitry that also shows the connections and indicators used. Shown in Figure 2, a quad op-amp (LM324) and a hex inverting Schmitt trigger (MM74C14) are used in the circuit to perform the following operations. One inverter is used as an oscillator by application of a resistor (R1) and capacitor (Cl) that forms and RC time constant that determines the frequency of oscillation. This oscillator drives the sensor circuit through a second inverter serving as a buffer. This signal is then split through a variable resistor (R2) dividing the voltage to the two legs of a modified RC bridge. The capacitive probe is connected to the circuit through a BNC connector (J1). One op-amp serves as a high gain difference amp that has as inputs the voltage across the two capacitors, C2 and the probe, which is an insulated metal plate as previously mentioned. The RC low-pass circuit (R4 and C2) with the contribution of R2 determine the set point. As a part of the child's body (hand for example) is moved closer to the probe, the capacitance at the probe increases. As the probe's capacitance reaches a value corresponding to a voltage at pin 2 equal to or exceeding that of the reference voltage at pin 3, the output at pin 1 of the op-amp goes low causing the output of pin 6 of the hex inverter to go high. The output voltage of this third inverter (denoted as Vo in Figure 2) can be used to drive an output transistor, FET, relay, or other output device. In Figure 2, the output Vo drives a relay of which the switch of the relay is accessed via a 3.5mm phono jack shown as J2. allowing for the connection of a toy, tape recorder remote, or other device that could then be turned on and off with the proximity device. The output of pin 1 of the op-amp is also sent to another inverter that drives an LED so when the relay is activated, the LED is on indicating an on state for the relay and the device it is controlling. The main advantages of this device as compared to commercially available units are its flexibility of probe design, adjustability of threshold level (position for activation), portability, size, and battery operation.

The total cost of the device including the cable and probe(s) is approximately $40 to $50 or less, depending on selection of enclosure, probe, connectors, and cable.

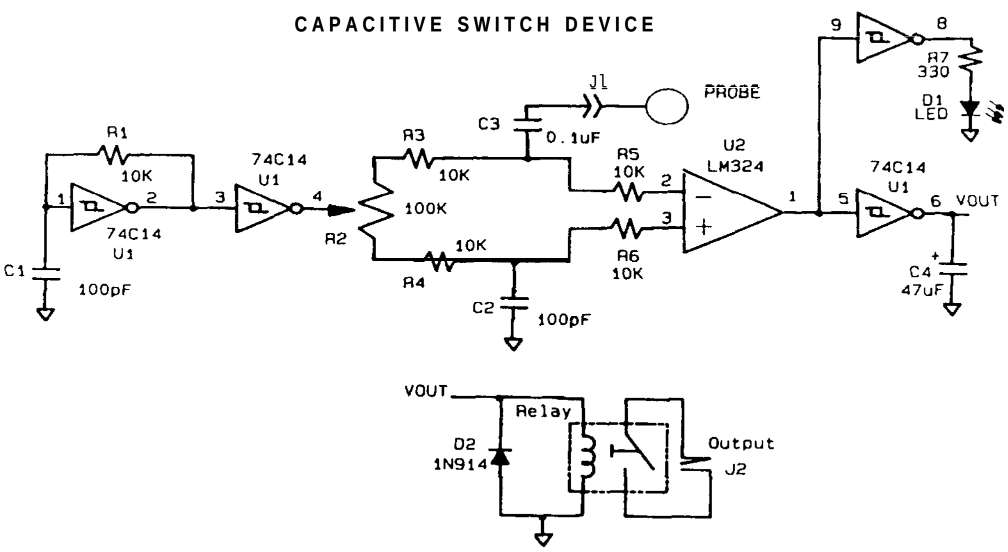

fig. 2. Schematic diagram of circuitry.

Computer Input/Output Interface for Apple II and IIe Computers

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INTRODUCTION

Caddo School for Exceptional Children has number of Apple II and IIe computers that they use for various learning tasks. However, there is a large variety of applications that the computers are not utilized for. The Apple computer game input/output (I/O) connector is a 16 pin DIP that provides for various switching inputs and outputs that could be used in a variety of applications dealing with evaluation training, and instruction. Yet, the limited access of the game I/O connector becomes a difficulty in the realization of the full potential of the device. This can be solved by the proper external interface allowing easy access to the I/O connector. The objective of this project was to design and build such an interface. Although some design work has been done, enhancements and modifications were needed that resulted in the present design

SUMMARY OF IMPACT

The present design is ready for field test. Since the previous design effort was successful, the device will provide the same opportunity while providing additional capabilities. This present design will allow for control of a wider range of devices, and also overcome some of the previous difficulties, This device will allow for additional software design of applications to meet various needs using the Apple computers without being restricted by I/O hardware access.

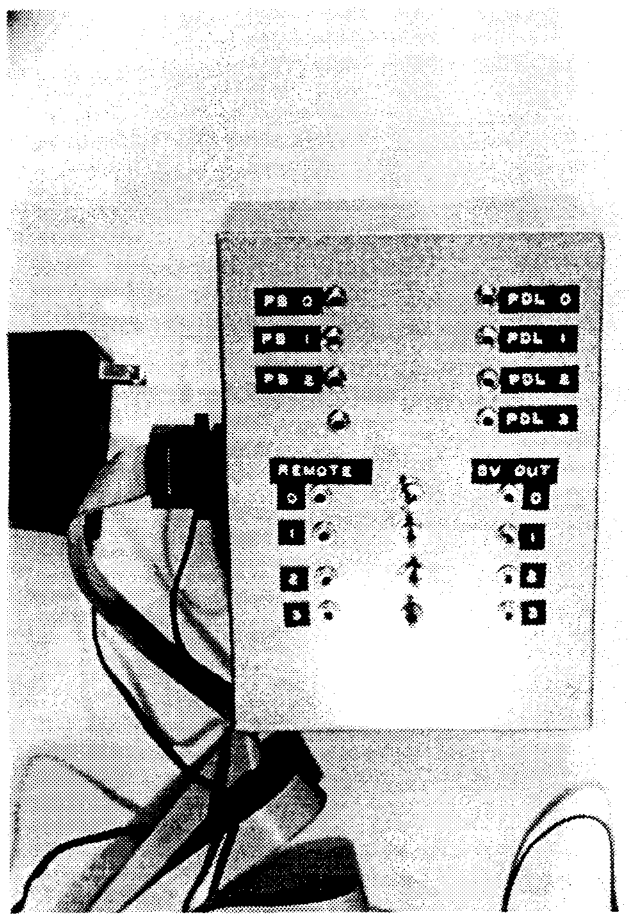

***Fig. 7. Computer input/output interface for** Apple **II** and IIe computers.*

TECHNICAL DESCRIPTION

The Apple computer's gameboard has a 16 pin DIP connector by which a variety of inputs and outputs can be accessed. As shown in Figure 1, the connector has 3 pushbutton inputs, 4 variable (joystick) inputs, and 4 annunciator outputs capable of 5 volt operation. Figure 2 is a diagram of the electrical circuitry. Last year, a similar device was manufactured; however, some problems were encountered during its use. Analysis of the information gained in the testing and evaluation of that device resulted in the present revision. In this version of the device, instead of a jumper cable, a D type connector is mounted to the back of the computer and connected to the gameboard's DIP connector. A corresponding connector is mounted on the I/O box and a cable mounted to its DIP connector. The box and gameboard are then connected by a standard D type connector cable assembly. A 1 Kohm resistor is connected to each pushbutton input to limit the current through the switch and provide a shunt for the input. As is shown in Figure 1, annunciator outputs; can be used in one of two modes. One mode is a simple 5 volt output. The other is a remote switch that can be used to turn on or off a tape recorder or some other device. Either mode can be selected by a switch and the annunciator can be turned on or off by use of peek and poke statements available within an Apple basic program. The SNL74LS241 is a noninverting octal buffer/driver for driving the 5 volt output to the switching device. This driver is used instead of the SNL74LS240 inverting driver that was used on the original device. On the original I/O vox reed relays with 1 amp contacts were used as switching devices. On this version power MOSFET's are used with 12 volt relays with 3 amp contacts and switching devices. A 3.5mm jack mounted on the I/O vox allows a 9 volt AC adapter (shown in Figure 1) to be plugged into the device. This connection provides the 5 volt power supply via a regulator, shown in Figure 2, and the excitation voltage for the relays directly. This allows greater flexibility in relays and output drivers without being limited by the power supply of the computer. To improve accessibility, a stand was mounted to the box, (Figure 1). The stand tilts the box at an angle of 30 from the supporting surface allowing for greater access and easier operation of the connectors and switches.

The total cost of the device is approximately $75.00.

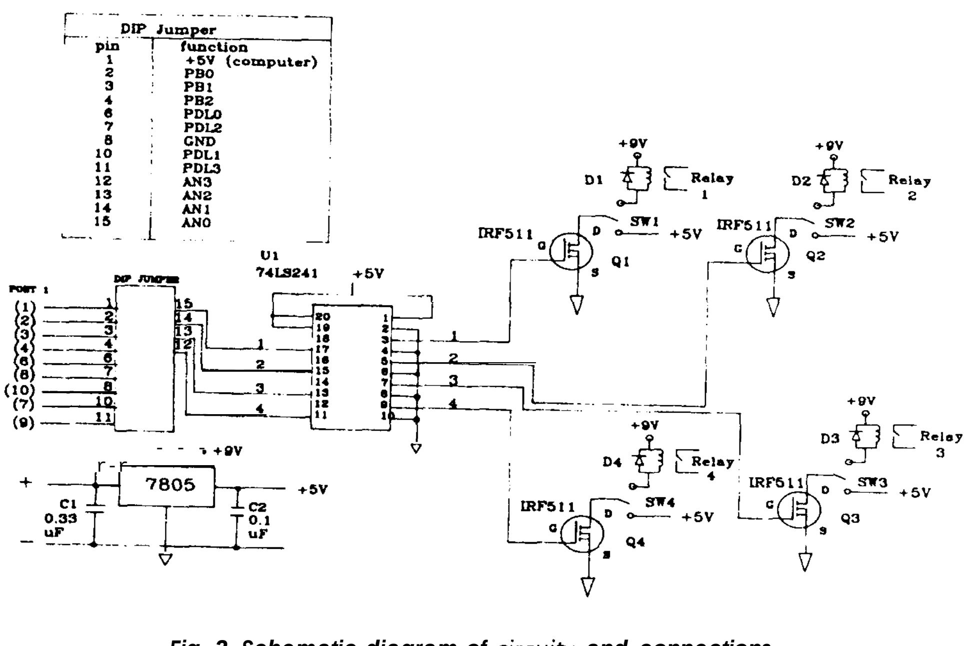

Fig. 2. Schematic diagram of circuity and connections.

Infrared Wireless Transmitter/Receiver System for Switch Input

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INTRODUCTION

When a handicapped child is utilizing a single switch input to operate a toy or other device such as a computer, a cable is usually used to connect the switch and device. There are some problems that result from the use of a cable. If the child is using a wheelchair for mobility, then the cable may have to be connected and disconnected, or the switch may have to be removed from the wheelchair when the child is moved to another location. Also, if the child is very young and/or has a severe cognitive deficit, then the child will usually play with the connecting cable which then becomes an obstacle to the training and development of the child. In these situations, it would be advantageous to have a wireless link between the switch and the device. This wireless link would allow the switch to be mounted on a wheelchair such that the child can operate a device with minimal, if any assistance. The wireless link also would provide for more effective training and development with very young children and/or children with severe cognitive deficit. There exists different mediums for a wireless link such as radio frequency, ultrasound, and infrared light. The device presented uses an infrared light medium to transmit the switch state to a receiver unit that controls the device.

SUMMARY OF IMPACT

The transmitter and receiver devices shown in Figure 1 have been in use with a variety of handicapped children. Although some problems and changes have been indentified, the device has demonstrated its usefulness and work has begun to incorporate the transmitter in other projects involving input devices. This wireless capability will provide increased independence for a variety of handicapped children.

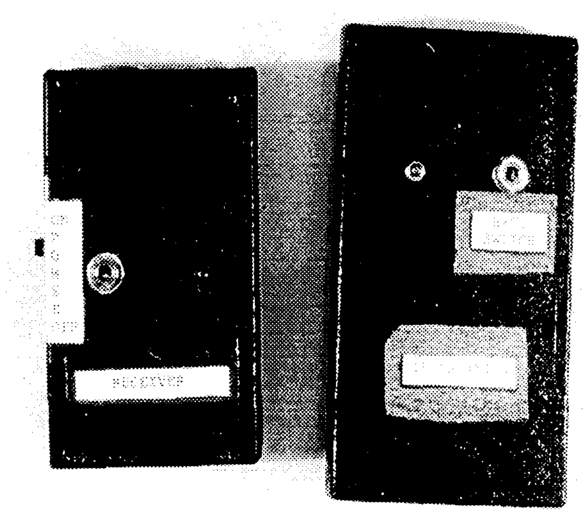

Fig. 1. Wireless, transmitter/receiver system consisting of transmitter (shown at left) and receiver (shown at right).

TECHNICAL DESCRIPTION

The infrared transmitter and receiver, as shown in Figure 1, forms a wireless link through which a switch can be utilized to operate a toy or other device or to interface with a computer without a wire or cable. The transmitter, shown a right in Figure 1 has a connector for the switch input and a test button to the left of the connector. The receiver shown in Figure 1 has an on/off switch and connector for the device to be controlled. The heart of the transmitter is a 556 dual timer, shown in Figure 2a. One section of the timer is set up as an oscillator with an output frequency of 40 kilohertz (kHz), the center frequency of the infrared detector's passband. The second timer of the 556 is set up as an oscillator with an output frequency of 1 kHz, which is used to enable the output of the primary oscillator. As a result, the output of the 40 khz oscillator is modulated at a rate of 1 kHz. The two oscillators constitute the driver for the infrared light emitting diode (LED) that will produce infrared light of approximately 980 nanometers. This light is the medium by which the 40 kHz signal modulated by the 1 kHz tone is carried to the infrared receiver's detector circuit. Control of the output of the transmitter assembly is provided by an external switch. When the switch is closed, power is fed to the 556 timer and the infrared output signal is produced. This is a power saving feature in that the LED and its driver circuity, which draw a relatively large amount of power, are only active when the device is actually transmitting a signal.

The receiver, shown in Figure 2b, consists of a GP1U52X infrared receiver/demodulator, a 567 tone decoder, and switching circuitry. The GP1U52X consists of an infrared detector combined with a filter and demodulator circuitry. The output of the detector diode is fed to a preamplifier circuit to boost the level of the signal and the resulting signal is fed to a filter circuit that rejects signal outside a particular passband (in this case the passband center frequency is 40 kHz). The output of the filter is fed to a demodulator circuit that removes the 40 kHz component, the result being a DC signal that can be fed to the remainder of the circuit. It should be noted that all of the above functions are performed by one device, the GP1U52X. The 567 is a phase-locked loop (PLL) device that is designed to produce a logic level output when the device detects a signal of a particular frequency, 1 kHz in this case. The only signal that will activate the receiver is an infrared signal carrying a 1 kHz tone. Without the tone decoder, it is much more likely that ambient noise will cause the output of the receiver to switch. The final portion of the receiver section is the external device switching section. The use of a relay for output provides for a broad range of controlled devices. Other methods tailored the particular device can be used such as a simple transistor output or an optoisolator output allowing isolated control of high voltage devices. The cost of the transmitter is approximately $15 to $20 and the cost of the receiver is about $20 to $25 resulting in a total cost for the device of about $35 to $45.

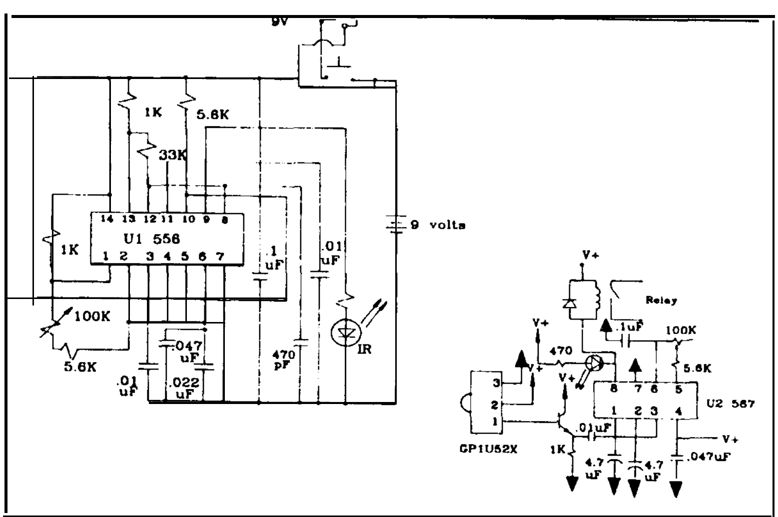

Fig. 2. Schematic diagram of (a) transmitter circuit and (b) receiver circuit.