INSTRUMENTATION & TECHNIQUES

A simple infrared photocell device and its interface to an Apple computer

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This paper describes a simple infrared photocell circuit that is inexpensive and easy to construct. The light source and detector are housed inexpensively and are focused so the light and detector may be separated over significant distances. The circuit may be used in a variety of conditions, including total darkness and bright fluorescent lighting, without having to readjust or recalibrate the circuitry. Output from the circuit may be used to drive other transistors or electro-mechanical relays. With minimal additional circuitry and hardware the signal may be interfaced with an Apple computer.

Activity has been an important behavioral measure in psychology and has been recorded with a variety of instruments, including devices that are physically attached to animals (Eisman, 1969) and those that monitor open-field movements electronically (Akaka & Houck, 1980; Pfister, Mudge, & Harcombe, 1978; Tarpay & Murcek, 1984). Photocells are also used and a number of commercial models are available (e.g., Coulbourn Instruments photobeam detector Model S23-01 and transducer Model T22-01, total approximately \$275; Lafayette Instrument Co. Model 85151, approximately \$278). Several "homemade" versions have been described (e.g., Gaustad, 1974; Uter, 1978), but most of these require a large number of electronic components. One exception is described by Clauson, Izatt, and Shimp (1985). However, few if any of the available reports describe how photobeams can be focused and detected over more than a short distance.

This report describes a simple infrared photocell device, an easy way to focus the photobeam, and a simple way to interface the photocell's output with an Apple IIe computer. Also included is a description of one type of software that has been used to record inputs from up to eight photocells.

PHOTOCELL CIRCUIT

Our goal was to build a photocell to detect activity of rats in various conditioning studies. The device we

The work described in this report was supported by Grant No. MH40976 from the National Institute of Mental Health to the first author. The authors gratefully acknowledge the helpful advice of Hayden Porter, who suggested the computer interface circuit shown in Figure 3.

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describe here has been reliable and very effective. Each unit consists of an infrared LED, an infrared phototransistor/detector, and circuitry to power both of these units and to switch an output whenever the photobeam is interrupted.

The circuit shown in Figure 1 includes a high-output infrared LED (Radio Shack part XC-880-A), an infrared phototransistor (detector, Radio Shack part TIL-414), and a circuit that provides the output signal. We used a 12-V dc power supply with the following component values: $R_1 = 560 \Omega$, $R_2 = 10 \text{ k}\Omega$, $R_3 = 50 \text{ k}\Omega$ potentiometer, $R_4 = 10 \text{ k}\Omega$, $C_1 = 1 \mu\text{F}$. However, the circuit can be constructed to use a variety of commonly available power supplies, including 24- and 28-V supplies. Power supplies with greater voltages should be used only with additional components to prevent overloading of the 741 chip. To determine the correct value for R_1 , use the formula $R_1 = (V - 1.5) / .020$ (R_1 is chosen to limit the current through the diode to 20 mA). To determine the value for R_2 , use the formula $R_2 = V / .0012$ (R_2 is chosen so that about 0.6 mA of emitter current will produce an emitter voltage of one half the power supply voltage). The

Figure 1. Complete circuit. LED = high-output infrared LED. PT = infrared phototransistor. 741 is an 8-pin integrated circuit.

value of R3, a variable resistor or potentiometer, is not critical; we suggest a value between 5 k Ω and 50 k Ω . The values of R4 and C1 are discussed below.

The infrared LED emits a steady light that can be detected by the phototransistor. When the phototransistor/detector receives the infrared light, its emitter current increases, and hence the voltage present across the emitter resistor (R2) increases. This voltage varies directly with the infrared input, however, and thus is not appropriate for digital switching. The phototransistor/detector's emitter voltage eventually is used as one of two inputs to the 741 chip. The other input determines the switching threshold and is some constant "comparative" voltage established from the power supply and ground with a variable resistor (R3). With these two inputs, the 741 functions as a voltage comparator, its output (pin 6) being in one of two states—minimum or maximum voltage. The maximum output voltage occurs when the voltage present at pin 3 (the + input) is greater than the voltage at pin 2 (the - input). This voltage will be approximately 1.5 V less than the supply voltage applied to pin 7. The output of the 741 is at its minimum voltage when the voltage at pin 3 is less than the voltage at pin 2. This minimum output will be approximately 1.5 V greater than the voltage applied to pin 4. The transition between output states takes a few microseconds. The setting of the variable resistor allows some adjustment of detector sensitivity. We achieved satisfactory performance by setting the voltage at pin 2 about midway between the voltage present at pin 3 with the beam blocked and that present with the beam on. The most appropriate setting can be determined by experimenting with various settings of this resistor.

The output signal from the 741 chip can be used to drive a transistor or an electromechanical relay as long as the output current limit for the 741 (about 18 mA) is not exceeded. If the signal is to drive a relay, the relay must be of the appropriate voltage and must be very sensitive, because the 741 signal can deliver very little power. Relays that require small switching currents (high-resistance relays) will work. Other relays can also be driven with the 741 signal, but an additional transistor must be added. (Contact the authors for a diagram and description.)

One problem in using photocells to monitor animal activity is the rate at which the circuit can switch its output signal. Very rapid interruptions of the photobeam (several hundred per second) might not be of interest and thus should not be counted. The R4 and C1 components eliminate the possibility of counting such "bursts." These components serve to place a maximum limit on the counting rate. The voltage at pin 3 of the 741 can shift no faster than a time approximately equal to the product of R4 and C1 (R in Ω , C in F, time in sec). For example, with R4 = 10 k Ω and C1 = 1.0 μ F, each counted event will be followed by a "dead time" of about 0.01 sec during which no additional counts are possible. Considerably longer dead times (e.g., 2 sec) can be achieved by changing the R4 and C1 units.

In building the circuit in Figure 1, the 741 should not be soldered directly. Rather, a socket should be used to facilitate the subsequent changing of the 741 chip. (We tried several 741 chips from Radio Shack, but none worked properly. We recommend 741 chips from Digi-Key Corporation, P. O. Box 677, Thief River Falls, MN 56701.) The total cost of components, including a small circuit board, was less than \$6.

Clauson et al. (1985) designed a circuit to detect pecking behavior of pigeons in front of a small visual display. The circuit described here is different from Clauson et al.'s in several ways. First, Clauson et al.'s circuit is designed for a single power-supply voltage, whereas a variety of power-supply voltages may be used with our circuit. Second, our circuit incorporates a capacitor (C1) that allows the duration of the output signal to be controlled. Finally, we describe a way in which the photobeam may be used over much longer distances than the photobeam described by Clauson et al.

HOUSING AND ALIGNING THE PHOTOCELL LED AND DETECTOR

Although the infrared LED emits light that is invisible to humans (and presumably to other animals), it operates much like an ordinary light bulb, broadcasting its light energy over a wide field. If the LED and the detector are to be separated by more than 1 or 2 in., the light energy must be focused with a lens. We housed the LED in a plastic PVC plumbing T tube obtained from a local hardware store. The tube is diagrammed in the top portion of Figure 2. Each opening of the tube measured 1 $\frac{5}{16}$ in. (inner diameter). A small hole was drilled at point A through which a screw was inserted. Inside the tube the screw secured a two-terminal barrier strip to which the LED had been attached. (To fit inside the T tube the edges of the strip had to be trimmed. The strip could also be fixed with cement or silicone sealant and some other type of connector could be used.) The LED pointed toward the opposite end (B) of the tube. A double convex objective lens (Fisher Scientific, 38 mm diameter, 5 cm focal length) was secured to this end with silicone sealant. The placement of the LED within the tube is critical. It must be pointed directly at the objective lens and it must be at the focal point behind the lens, as shown in the bottom of Figure 2. The focal point can most easily be determined simply by looking through the lens into the tube. The LED is in the correct position when the small metal leads within the transparent plastic LED are clearly in magnified focus. It may be necessary to bend the leads from the LED, but if the correct position is first estimated carefully, the hole can be drilled at point A so that only minor adjustments of the LED position are later required. Finally, leads attached to the barrier strip connectors allow the detector to be connected to the rest of the circuit. When the LED is adjusted behind the lens, the beam of infrared light is roughly 2 cm in diameter. This diameter seems ade-

Figure 2. Housing for the LED and phototransistor. Top shows measurements of the T tube and bottom shows focusing of the LED behind the lens.

quate for detecting gross activity of animal subjects, but may be too great to be useful in differentiating smaller units of movement.

We housed the transistor/detector in another T tube in the same way as described for the LED. With lenses focusing the light for both the LED and the detector, these two units can be separated by 1 or 2 m. Moreover, if resistor R2 is changed to a higher value, the effective distance of the photobeam can be increased. For example, with a 12-V supply, we used a 10-k Ω resistor for R2 and were able to count photobeam breaks over about 2 m. When we replaced R2 with a 200-k Ω resistor the circuit functioned properly with the LED and phototransistor/detector separated by about 7 m. Detection is also possible through water; thus, the circuit might be used with fish as well as with rodents.

Alignment of the two units is best accomplished by measuring the voltage across the two leads of the detector. A significant voltage shift occurs when the infrared LED is directed toward the detector. Because we planned to use the photocells for assessing activity of rats in transparent polycarbonate breeding cages, we secured each T tube to a wooden tabletop with an L-bracket screwed to the side of the tube and the table. Alternatively, the two tubes could be aligned and then secured to a wooden board or metal rod. The unit could then be moved without necessitating realignment of the two tubes.

We built eight pairs of housing units (for detector and LED) at a cost of about \$8 per pair.

COMPUTER INTERFACING

Hardware

The buffered output signal from the 741 was detected by an Apple IIe computer. However, the interfacing described could be applied to IBM-type machines with slight modification. The interfacing involved only two more units of hardware: an additional isolating device and a parallel interface card in one of the Apple slots. All circuits (photodetector, isolating device, and computer interface card) shared a common ground.

The additional isolation device was designed to prevent damage to the interface card and Apple from any accidental voltage surges from the photocell circuit. Isolation was accomplished with a 1489 chip. The 1489 is a "quad line receiver" designed to interface data terminal with data communications equipment. It is powered by a standard 5-V supply (in our case, from the Apple bus via the parallel interface card). The principal feature of the 1489 is its ability to receive inputs of ± 30 V dc and to produce outputs of logic 0 and logic 1 for computers.

The protection circuit we used is shown in Figure 3. The output from the 741 chip shifts between high and low voltages when the photobeam is broken. To shift between logic states, the 1489 requires that one of the input voltages be between about 2 and 25 V and the other considerably less than 1 V. In our lab, the 741 signal (V_{741}) shifted between about 10.5 and 1.5 V, a shift that the 1489 did not detect. Thus, to drive the 1489 adequately, a voltage divider (R5 and R6) should be installed. The correct resistor values will be determined by how much the 741 signal varies. To determine the proper R5 and R6 values, use the formula $(R6/(R5 + R6))V_{741} = V_{R6}$. The value of V_{R6} should be less than about 0.3 V when V_{741} is at its lowest value. And V_{R6} should be greater than about 2.0 V when V_{741} is at its highest value. For example, if V_{741} varies from 11 V (high) to 1 V (low), values of 12,000 and 4,000 Ω for R5 and R6, respectively, will result in voltages of 2.75 and 0.25 to drive the 1489 chip. We tried several 1489 chips from Radio Shack, but none worked properly; we recommend Texas Instruments' MC1489 chips.

Figure 3. Interface between photocell circuit and parallel interface card in the Apple. Values of R5 and R6 depend upon voltages from the 741 chip. Circuit shares a common ground with photocell circuit and the Apple.

Figure 4. Flow chart for capturing, storing, and displaying data with Apple assembly language program.

The parallel interface card contains two 6522 chips that provide a maximum of 32 bidirectional input/output lines plus independent timer/counters. This card, which has been described by Rhodes (1982), is available from John Bell Engineering (400 Oxford Way, Belmont, CA 94002) for approximately \$70. This versatile interface forms a critical part of the experimental control system reported by Rayfield (1982). In our lab, eight photocell units were constructed and fed into two 1489 chips. The eight outputs from the 1489s then led directly into eight input lines on the John Bell card. Each input corresponded to one bit of a single byte that could be read (e.g., PEEKed) under program control.

Software

Flexible 6502-based software systems that poll inputs and control outputs have been described previously (Rayfield, 1982; Rayfield & Carney, 1981; Rush, 1986). These systems operate with assembly language routines that interrupt processing every .01 sec to update timers and poll the various input lines. Our system differs from these in two major ways. First, we were not interested in controlling outputs, but only in polling the input lines and recording these signals over time. Second, checking the input lines was not initiated by the interrupt signal.

The John Bell card allows for accurate timing with an assembly language routine that operates by updating timer/counters each time an interrupt signal is generated by the card. The assembly code that operates this clock has been described by Rhodes (1982). Slight modifications to this clock routine were made for our lab so that the clock time was resolved to .1 sec. Clock time was continuously displayed on the monitor. The rest of the moni-

tor's screen was used to show activity counts for each of the eight photocells.

Instead of polling the input lines at every interrupt, the inputs were checked continuously as indicated in Figure 4. The byte reflecting the eight photodetectors was read and compared with the value of that byte the last time it was read. If all lines (bits) were the same as they were the last time the lines were checked, the byte was checked again. If one or more bits indicated a photobeam break, the assembly program determined which line(s) was (were) changed and then updated the data (activity counts) in the appropriate RAM data vector(s). Because the briefest photodetector signal lasted for a long time, roughly 0.01 sec, there was virtually no possibility of missing inputs. We have run the computer program simultaneously with independent electronic counters and have never noticed any data loss with the computer.

Cumulative activity counts are stored for each input line, as well as counts for every 5-min time bin during the recording period. If the maximum number of counts expected is relatively small, the time of each count could also be stored. However, this places great demands on memory because each counted event would occupy several bytes. The program allows recording times of a minimum of 30 min and a maximum of 8 h in ½-h increments.

At the end of the recording session, a BASIC program may be run to store the data to disk (in sequential files to save disk space). This program allows subject numbers and date information to be stored with the data to facilitate subsequent examination and analysis.

Listings of all BASIC and assembly routines are available from the first author at no charge. Knowledge of assembly language is necessary if modifications in the program are required.

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(Manuscript received July 29, 1986;
revision accepted for publication September 18, 1986.)