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An infrared device to monitor discrete ambulatory and stereotypic behaviors

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An electronic device that can detect discrete ambulatory and stereotypic behaviors of animals is described. The system involves a minimum of two infrared (IR) beams, each connected to a set/reset flip-flop or latch. The initial occlusion of an IR beam simultaneously sets a latch, delivers a locomotion pulse output, and resets any previously set latch whose IR beam is not occluded. A set latch causes its associated IR beam to be refractory to further locomotion movements until reset by the occlusion of a second IR beam. All beams are continuously responsive to stereotypic activity.

Changes in activity or location have long ranked among the most popular measures of animal behavior. These measures, in part due to the relative simplicity with which they can be automated, have played no small part in increasing objectivity and reliability in psychology. Of the numerous mechanical, electromechanical, and electronic methods of monitoring these behaviors, infrared-photocell devices have often proved to be among the simplest and least intrusive (Clarke, Smith, & Justesen, 1985).

Regardless of operational principle, most motion detectors provide a measure of general activity without classifying this activity into components. The majority of photocell-based devices, although biased toward measuring locomotion, cannot practically be made refractory to animals performing maintenance functions such as grooming while occluding a beam. A number of "hand-built" and commercial photocell-based devices are currently available that provide data on general activity (see Batson & Turner, 1986; Clarke et al., 1985). Only a few rather costly (\$2,500 and higher) commercial instruments (e.g., Columbus Instruments and Omni-Tech) are capable of distinguishing between locomotion and stereotypic activities such as grooming, preening, scratching, or digging.

This report describes a flexible, conceptually simple, and inexpensive infrared (IR) device that employs electronic circuits to dissect activity into its ambulatory and stereotypic components.

The Latched Photocell Circuit

An energized set/reset flip-flop or latch circuit can change state only when a signal appears on the specific line that triggers the opposite condition. This change cannot occur until after the line that initiated the original condition has gone low. Once the circuit has changed state, it then becomes refractory to other signals on the same line. If a photocell is wired in such a way as to set or latch a flip-flop and a second photocell is wired to reset or unlatch that flip-flop, the circuit will shift states as the photocells are sequentially occluded. Appropriate circuitry is capable of responding to stereotypic behaviors by monitoring the output of the photocells prior to the latch.

Consider the situation in which two photocell-triggered latches are connected so that setting one serves to reset the second and vice versa. If the latches are initially in the reset condition, then a subject's locomotion between the two photocells can be tracked by monitoring the set state of the latches. This concept is illustrated in the block diagram in Figure 1. Each photocell-activated flip-flop is connected through a pulse circuit (one-shot) and OR gate to the reset input of the opposite unit. If both flip-flops are in the reset mode, and if a subject is introduced into the activity arena, the set state of a flip-flop will thereafter coincide with the presence of the subject in that segment of the arena swept by the associated photocell (provided that the photocells are sufficiently separated that both can never be simultaneously occluded).

The system described above discriminates ambulatory from stereotypic activity on the basis of precedence. The initial pulse from a given photocell is always a locomo-

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Figure 1. The block diagram of an infrared device capable of distinguishing between ambulatory and stereotypic behaviors.

tion pulse. Subsequent pulses from that photocell are counted as stereotypic until the associated latch is reset by the occlusion of a second photocell.

An error circuit, consisting of the AND and XOR gate seen in Figure 1, discriminates stereotypic from ambulatory activity. The AND gate produces an output when it receives simultaneous stereotypic and locomotion pulses (the error condition). This minimizes the timing problems that can occur when performing the error function with the XOR gate alone. The XOR gate passes these stereotypic pulses, except when a coincident pulse is received from the AND gate.

Figure 2 shows the basic circuit of an activity monitor that is capable of distinguishing between ambulatory and stereotypic behaviors. Although able to stand alone, it is best viewed as an element of an array. Additional elements may be added to form a monitor of the desired resolving power (ability to detect small movements). Both the axial density of the IR-LED/phototransistor pairs and the separation between the LED and its detector may be greatly increased by use of focusing apparatus (see Batson & Turner, 1986). The geometry of the device is best determined empirically according to the size of subjects, number of axes, and desired resolution of movement. We have designed and built reliable IR devices without lens systems and with a density as high as eight beams on a single 24.5-cm axis (see Clarke et al., 1985).

Figure 2 shows high-output IR-LEDs (TIL 906-1) and sensitive phototransistors (TIL 414), which, given the circuit component values, may be separated by distances extending to a meter without focusing apparatus. The operational amplifiers (324) in Figure 2 are used for impedance matching and as comparators to provide noise rejection. The common-noise rejection level for both comparators is determined by the setting of a 500- Ω potentiometer. Changes in the output of the comparators is coupled through a 0.1- μ F capacitor to a 4071 OR gate, a 74221 one-shot, an AND and XOR gate error circuit

described previously, and a 4050 buffer. These circuit elements provide the stereotypic activity detection capability of the activity monitor.

The signals on the comparators in Figure 2 are also presented to two flip-flops that are constructed from four 4001 NOR gates. These flip-flops are set by the comparator outputs and, once set, can neither change state with the varying comparator input nor be reset as long as the comparator remains high (i.e., the IR beam remains occluded). The set outputs of the flip-flops are led to a dual one-shot (74221). The output from each of these one-shots is ORed and, after buffering (4050), provides the ambulatory activity detection capability. The one-shots also provide an error signal to differentiate stereotypic from locomotor pulses and a reset signal to return the previously triggered flip-flop to its initial condition.

As previously noted, a flip-flop cannot be reset if its set input remains high. This characteristic provides some flexibility in size of subjects for the activity arena. An animal in a multibeam arena can, therefore, occlude one or a number of beams simultaneously without causing a malfunction.

All flip-flops must begin operation in the reset state, or the initial position of the subject in the activity arena is indeterminate. The situation would be worse if all the latches on a common reset circuit were set and the device could not produce any locomotor pulses. To ensure against this eventuality, a button is provided to force the reset of all latches at the beginning of a session.

Discussion

The axial separation of IR-LED/phototransistor pairs is user determined, and multiple beams can be simultaneously occluded—as long as all beams are not simultaneously occluded. The latches receive a reset signal when a previously unoccluded photocell's latch goes from reset to set (each latch's set being tied through pulse circuits to the reset of every other latch). They cannot be

Figure 2. The basic schematic of the device described in the text. It can be elaborated to detect small increments of locomotion and fine stereotypic behaviors. For best operation, all one-shots (74221s) that track locomotor movement should be adjusted for slightly longer pulse widths than the one-shot(s) that track stereotypic movements.

reset, however, as long as their respective comparators remain high. In any given string of photocells whose latches share a common reset, it is vital that at least one latch be in the reset mode at all times. Violation of this restriction means that the condition described in the previous paragraph will exist. To ensure against this, the maximal size of any given subject (nose to tip of tail) must be less than the distance between the two most distal LED/phototransistor pairs whose latches share a common reset circuit.

The ultimate configuration of the dual-function motion detector will depend on how small a motion the user wishes to detect—and the size of his/her budget. The basic unit seen in Figure 2 may be constructed for under \$35. Our activity arena measures 34×34 cm and uses eight LED/phototransistor pairs (four per axis). The latches on

each axis are reset independently of the other axis to provide separate longitudinal and latitudinal locomotion measures. A single (combined x and y axis) stereotypic output is provided. Although this arena is designed for rats and mice, it may be used for any animal as long as the size caveat mentioned in the previous paragraph is observed. Since the IR beams are transmitted virtually unimpeded through water, Plexiglas, glass, or clear vinyl, smaller cages may also be placed inside this larger arena.

Motion detectors' outputs can be accumulated directly by LED readouts (see Figure 4 in Clarke et al., 1985), by various computer-counter interfaces (such as John Bell cards, which are available from John Bell Engineering, 400 Oxford Way, Belmont, CA 94002), or by electromechanical counters, provided the 74221s are adjusted to provide the longer pulse widths necessary with elec-

tromechanical devices. To prevent timing problems, the locomotion 74221s should be set to yield pulses at least 10% longer than the stereotypic one-shot(s).

It should be mentioned that it is also possible to use this device to detect locations and to follow the movement patterns of subjects in an activity arena. The simplest method of implementing this option is to construct a two-axis system of photocells and latches with a single digit of a printout counter tied to the set output of each latch. A set latch, representing the presence of a subject in the corresponding IR beam, will be seen on the printout as a column of 1s flanked by columns of 0s. For purposes of location accuracy, it is helpful if the subject is small enough not to occlude more than one beam on a given axis simultaneously. In a two-axis system, the subject would be located at or near the intersection of the IR beams represented by the 1s columns. The pattern of a subject's activities is seen in the progression of these filled columns over time.

Those readers who are familiar with programming microcomputers will have realized that it is at least theo-

retically possible to write a computer program that could separate the output from a bank of photocells into ambulatory and stereotypic behaviors. Solving problems through programming, however, involves numerous trade-offs among time, resolution, and reliability. We have found it to be generally more efficient to retain the microprocessor's memory and timing cycles for other tasks if a hardware solution is readily available.

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