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INSTRUMENTATION & TECHNIQUES

Automatic monitoring of temperature and/or location: A computer-controlled radiotelemetry system

ROBERT M. KAHN, WILLIAM FIFER, and RAE SILVER
Barnard College of Columbia University, New York, New York

A radiotelemetry system for continuous monitoring of the temperature and/or location of small animals is described. All the functions of system control are carried out by an on-line microcomputer (TRS-80 Model III), resulting in a versatile system capable of alternating recording the temperature/location of multiple subjects with other behavioral or physiological events, such as activity level. We describe the use of this system in monitoring body temperature in hamsters and in recording the incubation pattern of breeding ring doves.

The need to continuously monitor the temperature or the location of small animals occurs in many experimental paradigms. Radiotelemetry devices are available for monitoring core temperature in individual animals (Cunningham & Peris, 1983; De Castro & Brower, 1977; Hudson & Scott, 1979; Kamau, Johansen, & Maloiy, 1979; Randall & Thiessen, 1980; Thiessen & Kittrel, 1980) and for identifying individual animals housed in a group in the laboratory (Cadell, Cressman, Parsons, & Mills, 1972; Spelman, Jones, Bowden, & Spillane, 1980). Among other advantages, biotelemetry eliminates the handling involved in rectal temperature measurement, which elevates body temperature in rats (Cunningham & Peris, 1983).

Cummingham and Peris (1983) described a computerized system to record temperature data from single subjects implanted with a telemetry device. The design described here extends this application, merging radiotelemetry and on-line computer control to continuously monitor the temperature or location of several subjects simultaneously; when the system is used to track a single subject per cage, temperature and location can both be recorded. This system uses standard equipment and is relatively inexpensive. It provides flexibility in the number of subjects tracked and in the number and type of responses monitored, and it can operate without interruption for many weeks.

GENERAL SYSTEM DESCRIPTION

Battery-powered radio transmitters (Model X; Mini-Mitter Co., Sunriver, Oregon; length × diameter, 15 × 9 mm; weight, 1.2 g; cost, $40) are implanted to monitor temperature and location or are attached to animal subjects by harness to obtain physical location data only. As sold, the transmitter's signal is proportional to the temperature (.1° C resolution). For monitoring location, the telemeters are modified by the manufacturer to emit signals at a fixed rate. The signal of a fixed-rate telemeter can be set at a specified frequency for an additional fee. The battery (1.4 V) usually lasts from 2 to 3 months.

A diagram of the system is shown in Figure 1. Transmitter output is picked up by insulated copper wires (functioning as antennas) wrapped around relevant areas of the experimental cages. These cage antennas are coupled to an AM radio by connecting them to a wire wound around the radio's antenna loopstick. To control activation of the antennas, an electromechanical relay is inserted into each antenna circuit. By operating each relay in sequence, only one antenna is coupled to the radio at any time. The signals (heard as clicking sounds on the radio) are passed through the radio earphone jack into an interface circuit (Figure 2) designed to output a one-shot digital signal of fixed amplitude (5 V) and duration (30 msec) to the computer's input/output (I/O) port. The radio volume control is adjusted so that signals generated by the target subject, but not by subjects in adjoining cages, are strong enough to trigger the one-shot device. Lining the walls and floor of the cages with layers of aluminum foil or screen helps prevent cross talk between cages.

A TRS-80 Model III computer operates the antenna relays and monitors incoming signals via a commercially available I/O module (Interfacer 80; Alpha Products, Woodhaven, NY). Minimal computer configuration required is 16K with one disk drive. A complete "sweep" of all the cages is made by activating each of the antenna circuit relays in turn. The timing of the onset of each sweep and the duration of the sampling interval for each antenna are controlled by the computer's real-time clock; they are set according to the needs of the experiment and the number of antenna loops being monitored. Data are

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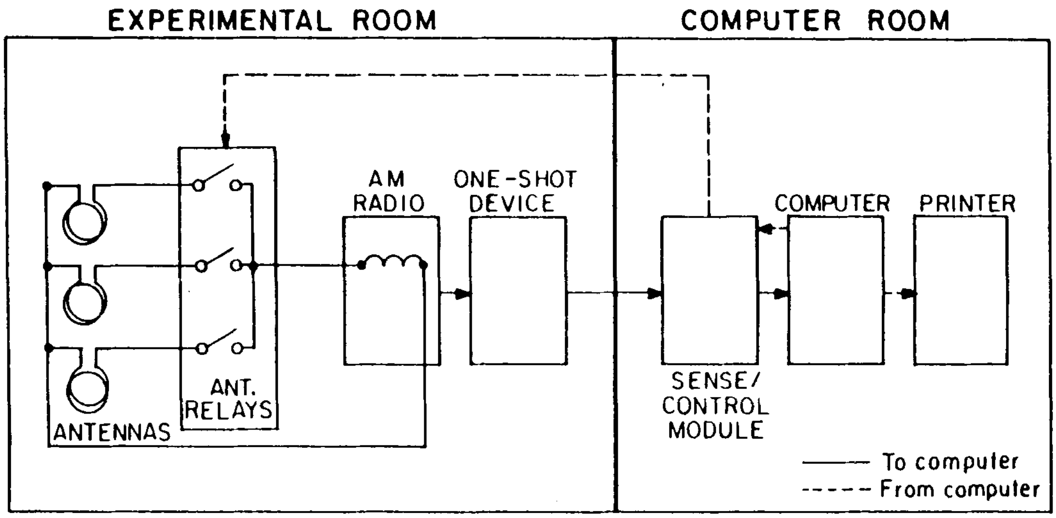

Figure 1. Schematic diagram of the computer-controlled radiotelemetry system.

printed and stored on floppy disk according to the demands of the experiment.

When a telemetric signal is sensed, a BASIC program (LOCATE.BAS or TEMP.BAS) calls a high-resolution Z-80 assembly language timing routine (TIMER.CMD) that is based on machine cycle time (4 MHz). TIMER.CMD measures the interval to a second pulse and passes the value of the interpulse interval (IPI) back to the LOCATE.BAS or TEMP.BAS program. IPIs are measured until a criterion of reproducibility of three consecutive IPIs of equal duration is met or until the sampling interval elapses. An appropriate code to indicate the status of the antenna (e.g., the value of the IPI) is then stored in an array.

Reducing Noise on the AM Band

The following measures increase the signal-to-noise ratio and successfully overcome the problem of occasional noise on the AM band. (1) The antenna wires are wound around the enclosed areas three times instead of just once, to increase signal strength. (2) The computer, a major source of radio frequency (RF) interference, is placed in a separate control room. (3) The antennas are run through a bank of relays to the radio. In order to minimize RF

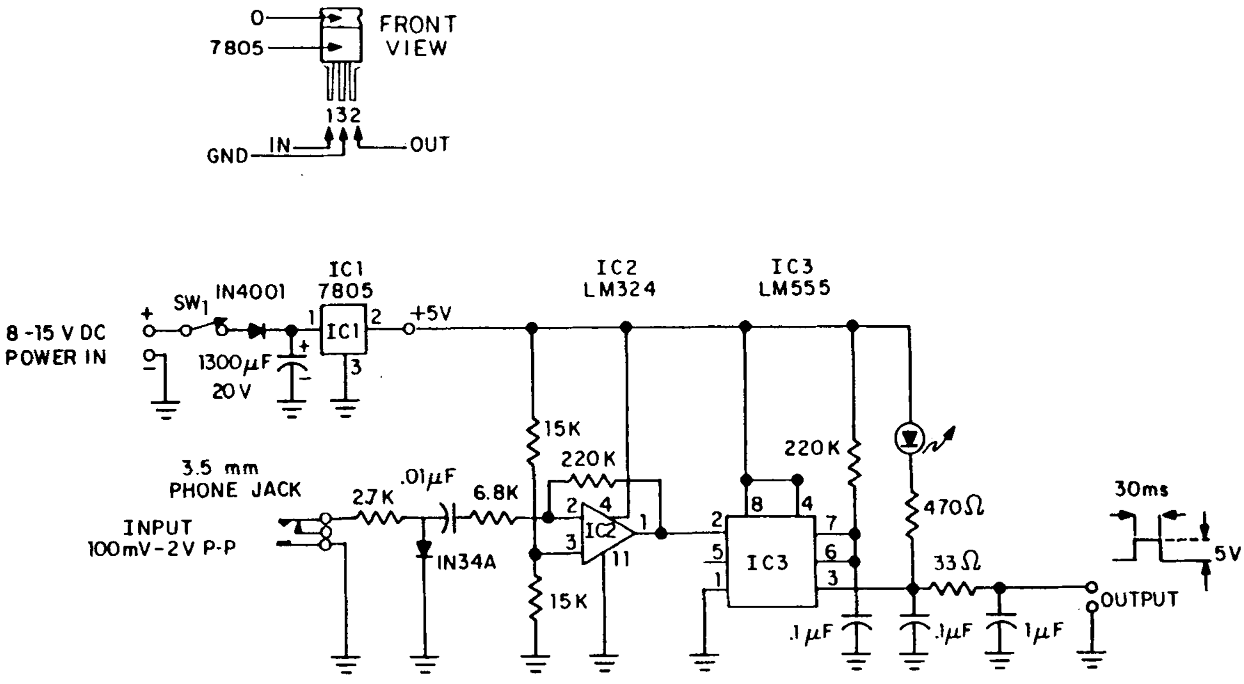

Figure 2. Interface circuit design. Radio pulse triggers a one-shot digital signal of fixed amplitude (5 V) and duration (30 msec).

interference, it is important to keep the antenna wires as short as possible. Thus, the relays and radio are placed near the experimental cages. (4) The one-shot device and the cables leading to and from the I/O module are grounded to the power supply in the experimental room. The effect of grounding these components has varied from system to system. (5) Finally, the criterion of reproducibility (described above) built into the computer software is designed to discriminate between the telemetric signal and background noise. An electronic interface circuit that differentiates between noise and telemetric signal should be considered in particularly noisy environments (De Castro & Brower, 1977).

MONITORING LOCATION

The computer-controlled radiotelemetry system has been adapted (Kahn, 1984) to monitor the location of each parent in experiments on timing of incubation in ring doves (*Streptopelia risoria*).

Preparation of the Transmitter

The telemeter is attached to a harness worn by the animal. The harness is made by securing a 2.5 × 2.5 cm patch of cloth to the back of the bird with elastic cord straps that loop around the base of the wings. The transmitter is placed in a plastic capsule for protection, and the capsule is glued to the cloth. Movements are unimpaired by the harness.

The telemeters (Model X) were modified by the manufacturer to emit signals at a fixed rate. The "fast" telemeters transmit between 3.5 and 4.5 pulses/sec; the "slow" group transmits between 2.5 and 3.0 pulses/sec. All male doves carry a transmitter in the "fast" range, and all female doves carry a "slow" transmitter.

Collecting Data

Six adjoining cages, each measuring 42 × 81 × 34 cm, are monitored by the system. Each cage contains an adult male and female ring dove, nest bowl, nesting material (straw), and two antenna loops. One antenna, monitoring the mate on the nest, surrounds the nest bowl (diameter = 9 cm). The other antenna, which records approaches to the nest by the nonsitting mate, encloses a rectangular hallway beside the nest (see Ball & Silver, 1983, for details of cage configuration). A partial barrier visually isolates the nest and approach area from the rest of the cage, where food, water, and grit are available ad libitum.

The computer activates each antenna one at a time in repeated 2-min sweeps of the six cages. During a sweep, a maximum sampling interval of 9 sec per antenna is enforced. A complete sweep of all of the antennas is made 29 times each hour, with the last 2 min of each hour reserved for storing data on disk and printing it out. If the signal from an antenna is "fast," then the data code for male is recorded in the data matrix; if the signal is "slow," then the code for female is recorded. The pulse rate usually meets the criterion of reproducibility within 3 sec. If both parent doves are within the antenna loop, then both signals are picked up, resulting in a continuous but irregular train of pulses recurring through the entire sampling interval; in this case, the criterion of reproducibility is not met, and the computer records the code for both subjects. If at any time during the sampling interval no signal is sensed for 3 successive seconds, or if fewer than five IPIs are measured, then the code for no subject in the area is recorded.

A separate program (LOCPRINT.BAS) reads the data from disk and prints out daily records of location. Figure 3 is a computer printout of the sitting behavior of a pair of doves housed under a light:dark cycle of 22:2. This represents part of a series of experiments investigating sitting duration as a function of photoperiod (Kahn, 1984).

MONITORING TEMPERATURE

This radiotelemetry system has also been used for continuous monitoring of temperature in adult male hamsters (*Mesocricetus auratus*) (Pickard, Kahn, & Silver, 1984).

Preparation of the Transmitter

Each hamster was implanted with a radiotelemeter (Model X) that emits signals at a rate proportional to the temperature. The transmitters were sealed against moisture with a paraffin-based material (Elvax; E. I. Dupont De Nemours and Co., Wilmington, DE). Subjects were anesthetized with pentobarbital (80 mg/kg), and the telemeters were placed in the abdominal cavity and secured to the abdominal muscle with a cyanoacrylate ester-based cement (Zipbond; Tescom Corp., Minneapolis, MN). Calibration curves were established for each telemeter before and after surgical implantation. This was done by placing each transmitter in a water bath at several temperatures between 20° and 45° C and recording the signal rate. The resulting curves were approximately linear throughout the range of temperatures tested.

Collecting Data

Six adult male hamsters were housed individually in plastic bins (44 × 24 × 20 cm) equipped with an activity wheel. The bins were contained in a light-tight box. The antennas were wound three times around the outside of each bin. Food and water were available ad libitum. Wheel-running activity was recorded on an Esterline Angus event recorder.

Body temperature was recorded at 15-min intervals. At the start of each quarter hour, the event recorder was automatically switched off by the computer (via the sense/control module) for 5 min because it generated considerable noise on the AM radio. During this time, the computer made one complete sweep, measuring the IPIs of the transmitter from each cage by operating each of

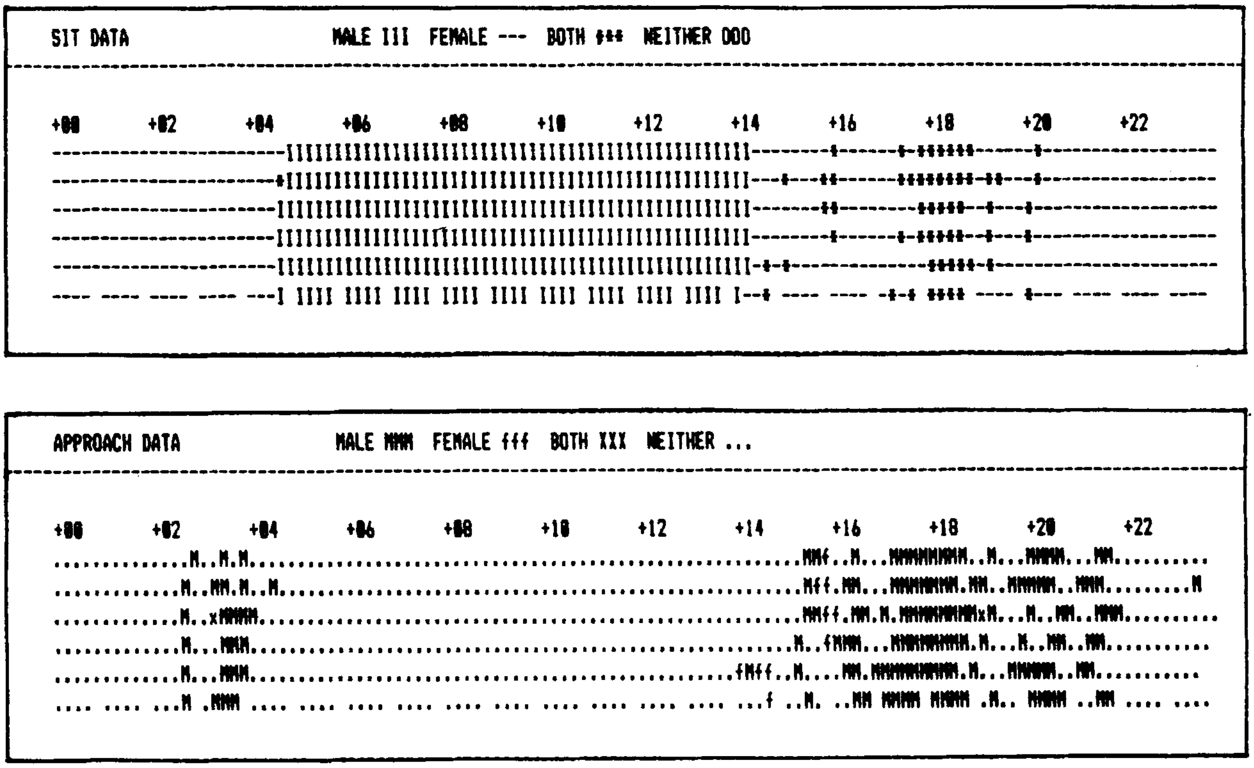

Figure 3. Computer printout showing the sitting pattern and nest approach behavior of a pair of doves recorded by radiotelemetry system over a 24-h period. Light:dark cycle is 22 h:2 h, with lights on at 0200 h. Each data point indicates the status of the nest area (top panel) or nest approach area (bottom panel) in 2-min "bins" (see text). Successive 2-min bins are listed downward within a column, each column consisting of six successive bins. From left to right in a row, data points in successive columns represent successive 12-min intervals.

the antenna circuit relays in turn. If the criterion of reproducibility was met, the IPI was recorded in the data array. The average latency to meeting criterion was about 8 sec in this experiment. If the criterion of reproducibility was not met within 45 sec (an infrequent occurrence), then the code for no data was recorded.

At the end of each day, data were stored on disk and printed out. The IPIs were subsequently translated into core body temperatures from the calibration curves established for each telemeter. A separate program (Autoplot; Menlo Systems, Palo Alto, CA) was used to draw continuous 24-h records of the temperature rhythm.

DISCUSSION

The radiotelemetry system described here has proved an effective and versatile means for long-term monitoring of body temperature and location in an avian and a mammalian species. In one application, we monitored the location of doves in order to identify which parent was incubating at each time of day (Kahn, 1984). In the other application, the system was used to monitor core body temperature of hamsters (Pickard et al., 1984).

If real-time data analysis is not required, a very inexpensive system for data acquisition can be made with a tape recorder (Kamau et al., 1979) to record telemetric signals for later analysis and electromechanical timers to activate the antennas. For small-scale studies or student labs, this approach merits consideration because of savings in time and money for system start-up.

Because the signal pattern generated by three transmitters cannot be distinguished from signals generated by two transmitters, this system is normally limited to tracking the location of one or two animals per cage (although they may be group housed). More subjects can be monitored simultaneously if the behavior of interest is confined to an area in which only one animal can reside at a time, such as a feeding or drinking bin (see Spelman et al., 1980). A system with crystal-controlled telemeters (Model T), although more expensive, permits the monitoring of more than two animals per cage. In such a system, each subject's transmitter is set at a different frequency in the CB range, and the computer can rapidly switch a multichannel reciever from channel to channel, making a sweep of all of the transmitter frequencies being used (Mini-Mitter Co., personal communication).

Connecting additional I/O modules to the computer permits more animals to be tested. Sampling the temperature four times an hour in 50 animals may be feasible, with the caution that more antennas increase the potential for RF interference. The computer can also be programmed to alternate recording temperature/location with other behavioral or physiologial events, such as wheel-running activity.

SOFTWARE AVAILABILITY

A complete listing of LOCATE.BAS, TEMP.BAS, and TIMER.CMD is available from R. Kahn, Department of Psychology, Barnard College of Columbia University, 606 W. 120th Street, New York, New York 10027.

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