Recent advances in microcomputer technology and in the miniaturization of electrical circuits have led to a great increase in the applications of radio telemetry to wildlife research and management (White and Garrott 1990). These advances have influenced standard techniques for radio telemetry and have included the increasingly widespread use of satellites to monitor wildlife populations (e.g., Fancy et al. 1988, Garner et al. 1989). Satellite telemetry can provide limited information on animal activity (e.g., migration movements; Fancy et al. 1989), but it is not yet of much use to biologists who require detailed activity information from nonmigratory animal populations. For the most part, researchers studying animal activity patterns must still depend on more traditional telemetry techniques.

Some researchers have used microcomputers to record activity information directly from a telemetry receiving system (e.g., Cupal and Weeks 1989) or to interpret tape recordings of telemetry data (Nams 1989). The more successful applications of computer-based recording systems have involved either infrequent signals (e.g., Howey et al. 1989) or the recording of signals that are specific to individual activities (e.g., Bevins et al. 1988). Frequently, discerning specific activity patterns from telemetry information requires extended segments of data (Gillingham and Bunnell 1985, Beier and McCullough 1988); the associated volume creates extensive data processing problems. The cost and lack of portability of computer-based data recording systems, as well as the overall simplicity of strip-chart recorders in remote field recording systems, favor the continued use of chart recorders for recording animal activity. Chart recorders also will continue to prove useful in radio-telemetric monitoring of physiological in-
Fig. 1. Schematic representation of our data recording system including the timing circuit. The timer and relay circuit are connected to the amplitude wire between the digital processor and the chart recorder. R1 represents a 12-VDC relay, T1 the reset timer device, and S1 a single-throw switch. Closed circles represent connected wires; the numbers within T1 are the connection points on the reset timer device. The relay is connected to the timer so that the circuit from the processor to the chart recorder is normally closed.

Indicators such as body temperature and heart rate, weather stations, and the collection of stream discharge information.

The major disadvantage of non-computer-based recording systems is that time is not known accurately and must be assumed from a constant chart speed. Various timing devices have been described for ecological applications. For example, Jenness and Ward (1985) described a timer for recording elapsed time after an event, and Göransson (1980) reported on the use of timers to turn telemetry equipment on and off in the field. Attempts to combine time and strip-chart data in field applications have been limited (e.g., Gaardmand and Jeppesen 1984), and, for the most part, errors associated with fluctuating speeds of chart recorders in the field are undocumented. Herein, we describe the variation in speed within and between 2 identical chart recorder systems and describe an inexpensive timing circuit that can be added easily to existing telemetry systems to increase reliability of the data.

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METHODS

We obtained our data as part of an extensive study conducted on the bioenergetics of free-ranging black-tailed deer (Odocoileus hemionus columbianus) near Wrangell, Alaska (56°22'N, 132°10'W). We placed radio collars, containing a head-up and head-down tip-switch and an inactivity sensor (Model MOD-500; Teledyne, Mesa, Ariz.), on 9 deer. All animals
roamed freely over an approximately 130-ha
island. Telemetry information was recorded
from a receiving station approximately 2 km by
water from the island.

Each of 2 receiving systems consisted of an
omnidirectional antenna (Model RA-6B; Teloni-
cics, Mesa, Ariz.), a TR-2 receiver and TPD-2
digital processor (Telonics, Mesa, Ariz.), and a
Rustrak® dual-channel strip-chart recorder (Se-
ries 300; Gulton Industries, Manchester, N.H.)
geared to run at 5.08 cm/hour. We used WAA
strip-chart paper (Telonics, Mesa, Ariz.). After
noting substantial differences in the speeds of
the supposedly identical chart recorders (Gil-
ingham, Univ. of Wyo., unpubl. data), we add-
ed a timing circuit to the system (Fig. 1). This
circuit was connected to the amplitude wire
between the digital processor and the chart re-
corder. In our application, the amplitude infor-
mation passed undisturbed to the chart recorder
for 59 minutes out of every hour. Every sixty-
ith minute, however, the timing circuit opened the
connection between the processor and chart re-
corder. The result was a 1-minute timing mark
on the amplitude side of the strip chart (Fig. 2)
every 60 minutes.

The main component of the timing circuit
(Fig. 1) was an adjustable reset timer (Model
RS1A22; SSAC Inc., Box 1000, Baldwinsville,
N.Y.) in which dip-switches could be altered so
that the timer was on from 0.1-102.3 minutes
and off from 0.1-102.3 seconds. We used a sim-
ple 12-VDC (volts direct current) relay (Coil:
320 Ω, 37.5 mA; Model #275-241; Radio Shack,
Fort Worth, Tex.) to reverse the effect of the
timer on the amplitude circuit. Consequently,
when the timer was on, the relay opened and
the amplitude channel of the chart recorder re-
ceived no voltage, resulting in a dot (hereafter
a timing mark) on the strip chart; as long as the
timer was off the amplitude information was
passed directly to the chart recorder. Thus, by
setting the timing circuit to be on for only 1
minute/hour, we did not lose amplitude infor-
mation if the timer failed, as might happen if
we did not incorporate the relay into the circuit.

We used a simple toggle switch (S1 in Fig. 1)
to synchronize the timing marks on the strip-
chart recorder with actual clock time. When we
opened and closed the switch the timer was
reset. Generally, we reset the timer once every
24 hours ending an individual trial. Over the
course of the continuous 2½-year monitoring
period, however, we let the system run on the
same animal for 11-15 days on 4 occasions.

We determined the actual duration of the on
and off sequences of each timer by counting the number of timing marks per known period each time we reset the systems. We analyzed all tapes using our own BASIC software and a 48-inch Digitizing tablet (Model 9148; Calcomp Inc., Anaheim, Calif.) equipped with a 16-button cursor for data input. First, after inputting the average time between timing marks (in seconds), we entered the location of the start of each hourly timing mark on the strip chart with the 16-button cursor. These locations (± 0.025 mm) were saved to an output file for the analyses presented in this paper. Second, we touched the 16-button cursor to each change in activity on the strip chart; we used a distinct button for each activity level (i.e., active, inactive, unknown). The program then wrote a separate output file for each individual recording of an animal including each behavior, duration of the behavior, and the starting time of that behavior.

During the recording period, we used 2 different battery configurations to power the telemetry systems. For the first 67 days of the data presented in this paper, both telemetry systems were powered by 1 12-VDC marine battery. On 6 September 1989 we separated the systems and used 1 battery/telemetry system for 67 days. Each system was powered by a separate battery for the final 380 days.

Table 1. Measured chart speeds for 2 Rustrak® recorders (A and B) geared to advance at 5.08 cm/hour.

<table>
<thead>
<tr>
<th>Chart recorder</th>
<th>No. batteries b</th>
<th>Chart speed (cm/hr)a</th>
<th>n0</th>
<th>±</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1</td>
<td>1</td>
<td>1,240</td>
<td>6</td>
<td>4.44 ± 0.28</td>
<td></td>
</tr>
<tr>
<td>A 2</td>
<td>2</td>
<td>7,767</td>
<td>6</td>
<td>4.31 ± 0.23</td>
<td></td>
</tr>
<tr>
<td>B 1</td>
<td>1</td>
<td>1,195</td>
<td>6</td>
<td>5.63 ± 0.77</td>
<td></td>
</tr>
<tr>
<td>B 2</td>
<td>2</td>
<td>8,112</td>
<td>6</td>
<td>5.49 ± 0.63</td>
<td></td>
</tr>
</tbody>
</table>

a Individual chart speeds measured by digitizing procedure described in text.
b Both telemetry systems ran on 1 12-VDC deep-cycle marine battery for 67 days. Each system was powered by a separate battery for the final 380 days.

* n = average timing marks (1-hour periods) measured for each chart recorder and battery combination.

RESULTS

To assess how the chart speed varied within a trial, we examined all trials when the recorder was left on 1 animal for more than 5 days (longest 15 days; n = 28 trials). We then used Pearson correlation analysis (SAS: CORR 1987) to examine relationships between the speed of the tape per timing-mark interval and the timing-mark number in a given trial. We used a separate analysis for each Rustrak® recorder. For this analysis we only used data when the systems were powered by separate batteries.

Two identically geared chart recorders differed (Machine 1: 4.32 ± 0.25 cm/hour [± SD], n = 9,007; Machine 2: 5.49 ± 0.65 cm/hour, n = 9,307; F = 26,007.81; P < 0.001) in the distance the paper moved per hour; average chart speeds also differed (F = 163.75; P < 0.001) when they were powered by separate batteries compared to when they shared a common power source (Table 1). There was no statistical interaction (F = 1.10; P = 0.294) between the chart recorder speed and the number of batteries powering the system, nor did we see any difference in the time between timing marks (Timer A: 3,641.93 ± 25.64 sec [± SD], n = 255; Timer B: 3,641.24 ± 25.65 sec, n = 265; P = 0.629). The time between timing marks on each machine, however, was affected (F = 762.68; P < 0.001) by the number of batteries powering the system.

The use of the timing marks enabled us to determine that the chart speed of each recorder changed within runs of 5–15 days and that the 2 machines behaved differently under these conditions. For Machine A, we observed a negative correlation between the speed of the machine and the number of timing marks in the trial (r = −0.238; P < 0.001; n = 2,326), meaning that the recorder tended to slow down with time. In contrast, the greater the number of sequential days in a trial, the faster Machine B tended to run (r = +0.167; P < 0.001; n = 2,098).

Besides increasing accuracy, our combined use of timing marks and digitizing of data greatly reduced the amount of time needed to analyze strip charts. We could process an entire tape in 2–3 hours. Because the data were written to computer files, any further data entry steps also were eliminated. This timing system costs approximately $50.00, and the on and off timing sequence can be modified easily in the field without changing any of the circuit’s components.

DISCUSSION

Without the addition of the described timing circuit to our activity-recording system, we would have incorrectly assumed a constant chart
speed and consequently introduced errors into
our interpretation of the activity data. Assuming
a constant chart speed before we installed the
timers, we used linear interpolation between
known times to estimate the times of activities.
Often, no end time was known when a chart
recorder was not working properly. We then
were forced to assume that the chart recorder
was advancing at the factory-specified rate. Our
data show that this would have been an incorrect
assumption for these machines.

We observed that the 2 chart recorders
changed speed in response to declining voltage
(i.e., longer trials) and that they responded dif-
ferently to changes in voltages ranging from
12.8 VDC down to 12.3 VDC. Machine A, which
ran at the slower chart speed (Table 1), slowed
during longer unattended periods; the second
chart recorder (Machine B) increased speed.
We believe the latter may have resulted from
the machine being less sensitive to voltage, and
as the amount of paper on the supply roll de-
creased, the gears advanced the decreasing
amount of paper at a faster speed.

We also observed large amounts of variation
(up to 30%) in the distances between consecutive
timing marks on a chart tape; recorders did not
advance at a constant speed. Temperature, volt-
age, and the amount of remaining paper may
have contributed to this variation. To our knowl-
dge, variation in chart speed only has been
reported as a problem in recording activity in-
formation by Gaardmand and Jeppesen (1984),
despite the extremely wide use of similar re-
cording systems in research and management.

The timing system we describe was precise
and only about 40 seconds over the timing in-
terval we specified with the dip-switches. We
believe that both the precision and the accuracy
of the system could be increased by substituting
a "time-of-day" timer instead of the elapse tim-
er that we used. For most applications, however,
the accuracy of the described timing system
should be adequate.

RESEARCH IMPLICATIONS

Biologists using chart recorders to collect ac-
tivity information from remote telemetry sta-
tions must assume that the chart speed is con-
stant when interpreting their data. Our results
show that for the 2 machines that we used, this
was not true. Neither of our machines per-
formed at the speed specified with the gearing
system. The addition of a simple timing circuit
that marks time on the amplitude portion of the
strip chart would improve the reliability of in-
terpreting time and activity from chart records.
Additionally, the time at which a chart recorder
fails or runs out of paper can be determined
using this system. Finally, our use of a digiti-
zation procedure based on timing marks en-
abled us to decrease significantly the time nec-
essary to encode data from the strip charts.

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