Technical Note

An Advanced, Low-Cost, GPS-Based Animal Tracking System

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Abstract

An improved global positioning system (GPS)–based animal tracking system is needed to meet quickly evolving demands of ecological research, range livestock production, and natural resource management. Commercially available tracking systems lack the data storage capacity needed to frequently collect animal location data (e.g., 15-minute intervals or less) over long-term deployment periods (e.g., 1 year or more). Some commercial systems have remote data–download capabilities, reducing the need to recapture tagged animals for data retrieval, but these systems download data via satellite (Argos), global system for mobile communications (GSM) cellular telephone, or telemetry radio frequencies. Satellite systems are excessively expensive, and GSM cellular coverage is extremely limited within the United States. Radio-based systems use narrow-band very-high– or ultra-high frequencies requiring the user to obtain frequency allocations. None of these existing systems were designed to provide continual, real-time data access. The Clark GPS Animal Tracking System (Clark ATS) was developed to meet the evolving demands of animal ethologists, ecologists, natural resource managers, and livestock producers. The Clark ATS uses memory-card technology for expandable data storage from 16 megabytes to 8 gigabytes. Remote data downloading and program uploading is accomplished using spread-spectrum radio transceivers, which do not require narrow-band radio frequency allocations. These radios also transmit, at a user-defined time interval, a real-time, GPS-location beacon to any Clark ATS base station within range (about 24 km or 15 miles line of sight). Advances incorporated into the Clark ATS make it possible to evaluate animal behavior at very fine spatial- and temporal-resolution over long periods of time. The real-time monitoring provided by this system enables researchers to accurately examine animal distribution and activity responses to acute, short-term disturbances relative to longer-term behavioral patterns. The Clark ATS also provides a huge time- and cost-savings to researchers and natural resource managers attempting to relocate a tagged animal in the field for direct observation or other operations.

Resumen

Se necesita un sistema mejorado de rastreo de animales basado en GPS para satisfacer las crecientes demandas de investigación ecológica, producción de ganado en pastizales y el manejo de los recursos naturales. Los sistemas de rastreo comerciales disponibles carecen de la capacidad de almacenaje de datos necesaria para colectar frecuentemente la localización del animal (por ejemplo, a intervalos de 15 minutos o menos) en un período largo de tiempo (un año o mas). Algunos sistemas comerciales tienen capacidad de descargar datos a larga distancia, reduciendo la necesidad de recapturar los animales marcados para recuperar los datos, pero estos sistemas descargan los datos vía satélite (Argos), a través de telefonía celular GSM o de radiofrecuencias de telemetría. Los sistemas de satélite son excesivamente caros y la cobertura de la telefonía celular GSM es extremadamente limitada dentro de Estados Unidos de América. Los sistemas basados en radio usan bandas estrechas de frecuencia VHF o UHF, requiriendo que el usuario obtenga asignaciones de frecuencia. Ninguno de los sistemas existentes fueron diseñados para proveer un acceso continuo en tiempo real. El Sistema de Rastreo de Animales Clark GPS (Clark ATS) fue desarrollado para satisfacer las demandas de los etólogos animal, ecólogos, manejadores de recursos naturales y productores de ganado. El Clark ATS utiliza tecnología de tarjeta de memoria para expandir la capacidad de almacenaje de datos de 16 megabytes a 8 gigabytes. La descarga remota de datos y la carga del programa se logra usando radio transcriptores de espectro amplio, que no requieren la asignación de frecuencias de radio de banda angosta. Estos radios también transmiten, a un intervalo de tiempo definido por el usuario, en tiempo real, la localización de la baliza de GPS a cualquier base de Clark ATS dentro del rango (aproximadamente 24 km o 15 millas en línea recta). Los avances incorporados al Clark ATS hacen posible evaluar el comportamiento animal a una resolución espacial y temporal muy fina por largos períodos de tiempo. El monitoreo en tiempo real suministrado por este sistema permite a los investigadores examinar acertadamente la distribución de los animales y las actividades en respuesta a disturbios severos a corto plazo en relación a los patrones de comportamiento a largo plazo. El Clark ATS también proporciona grandes ahorros de tiempo y costos a los investigadores y manejadores de recursos naturales que intentan relocalizar en el campo a los animales marcados para realizar observaciones directas u otras operaciones.

Key Words: activity budgets, animal behavior, global positioning system, habitat use, real-time, telemetry tracking

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INTRODUCTION

Study of animal ecology using telemetry tracking systems began in the late 1950s and early 1960s (Le Munyan et al. 1959; Eliassen 1960; Marshall et al. 1962; Cochran and Lord 1963; Mech et al. 1965) using collars or tags emitting very-high frequency (VHF) radio-signal pulses. Intensive monitoring of widely roaming animals with VHF systems, however, was costly, time-consuming, and often posed risks to personnel safety. With the launch of the Nimbus 3 satellite (Kenward 1987) and, later, the Argos system (Fancy et al. 1988), it became possible to automatically collect and transmit location data from widely roaming or migrating animals (e.g., polar bear and caribou) using satellite communication technology (for examples, see White and Garrott 1990). The positional accuracy of these location data, however, was quite coarse (± 300 m) (Britten et al. 1999), thus negating their use for habitat-selection studies. Deployment of the NAVSTAR (Navigation Geographic Positioning System [GPS]), declared fully operational in 1995, enabled development of animal tracking systems with unprecedented positional accuracy (± 5 m) (e.g., Rodgers et al. 1996). These GPS-based tracking systems allowed evaluation of animal movement and habitat selection at very fine spatial resolution.

Despite these technological advances, however, telemetry tracking systems have not kept pace with the evolving demands of ecological research. Costs of commercial GPS tracking collars severely limit the sample size (i.e., individual animals) and statistical power that researchers have available for animal ethology and ecology studies. Commercial GPS collars also have data-storage constraints that hinder collecting location data with high-temporal frequency (e.g., every 15 minutes or less) over long deployment periods (up to 1 year or more). Consequently, intensive investigations of habitat selection, short- and long-range movements, and other animal behaviors cannot be conducted over multiple seasons or years without frequently downloading and erasing data from the collar memory. Some commercial systems have remote data–download capabilities, reducing the need to frequently recapture collared animals for data retrieval. These systems, however, download data via satellite (e.g., Schwartz and Arthur 1999), global system for mobile communications (GSM) cellular telephones, or telemetry radio frequencies (Rodgers et al. 1996). Satellite communication is very expensive. The GSM cellular coverage in the wildlands of North America is extremely limited. Radio-based systems use narrow-band VHF or ultra-high frequency (UHF) requiring the user to obtain frequency allocations, which dictate where and when these systems can be used. None of these existing systems were designed to provide the continuous, real-time data access that is often desired by ecologists, animal ethologists, and other researchers.

The objective of this research was to develop a robust GPS-based, real-time animal tracking system with the following attributes: 1) individual collars and mobile base-station units costing less than $1 000 each (US dollars in 2006); 2) spread-spectrum radio frequency communication between collar and base station allowing remote uploading of programming and downloading of postdifferentially correctable GPS data; 3) real-time collar tracking capabilities where GPS data describing the current location of the collar would be transmitted via spread-spectrum radio to a hand-held base station capable of receiving and displaying collar locations on a digital map; 4) collar units having a large (up to 8 gigabyte), user-expandable, on-board data storage capacity; and 5) collar components having very low power demand (mean consumption < 100 mW) and batteries with very high capacity (19 AH D-cells). The relatively low cost of the Clark GPS Animal Tracking System (Clark ATS) would help the user to economically deploy the system on an adequate sample size of animals, which may not have been possible using a more expensive, commercial tracking system. The capabilities of the Clark ATS would also allow the user to deploy the system for up to 3 weeks at a data-capture rate of once every minute without the need to recollect and service the collar. For longer-term deployments, the user could configure the system to acquire data at 15-minute intervals for up to 1 year without service.

MATERIALS AND METHODS

Clark GPS Animal Tracking System

The Clark ATS consists of a GPS tracking collar (Fig. 1) and a hand-held, mobile base station (Fig. 2). The tracking collar collects and stores GPS-fix information including collar location (latitude and longitude), date and time (Greenwich mean), and parameters indicating fix quality (e.g., dilution of precision and number satellites used) on a removable memory card (CompactFlash) contained within the collar. Raw satellite data (e.g., carrier phase, pseudorange, and Doppler measurements) acquired and used by the GPS receiver to calculate a GPS fix are also stored on the memory card allowing postdifferential correction of the GPS locations for improved spatial accuracy. Use of the removable memory card for data storage allows the user to quickly remove data from the collar while still in the field. Changing the data storage capacity of the collars for different applications is as simple as inserting a memory card with a different capacity.

The collar and hand-held base-station units are wirelessly linked by radio transceivers. These radio transceivers operate in the spread-spectrum radio bandwidth (902–928 MHz). Spread-spectrum radio transceivers can frequency-hop throughout this wide bandwidth looking for an unused frequency for data transmission (Ziemer et al. 1995). Frequency-hopping helps maximize successful and timely data transmissions and eliminates conflicts, even when many different users are in the same coverage area. Besides collecting and storing raw GPS-fix information described above, the collar also collects GPS-fix data that have been differentially corrected, in real-time, using the wide-area augmentation system (WAAS). The collar then transmits these WAAS-corrected data to a Clark ATS base station via the radio link. In this way, the collar is transmitting a differentially corrected GPS location beacon to any base station within range, allowing real-time tracking of the collar location. Collar location data received by the base station are stored in an electronic database on the base station for later use. These location data may also be plotted in real-time on digital topographic maps and orthophotographic images using base-station software. The radio transceivers also make it possible to remotely download data stored on the collars and to remotely upload new programming to the collar from the base station.

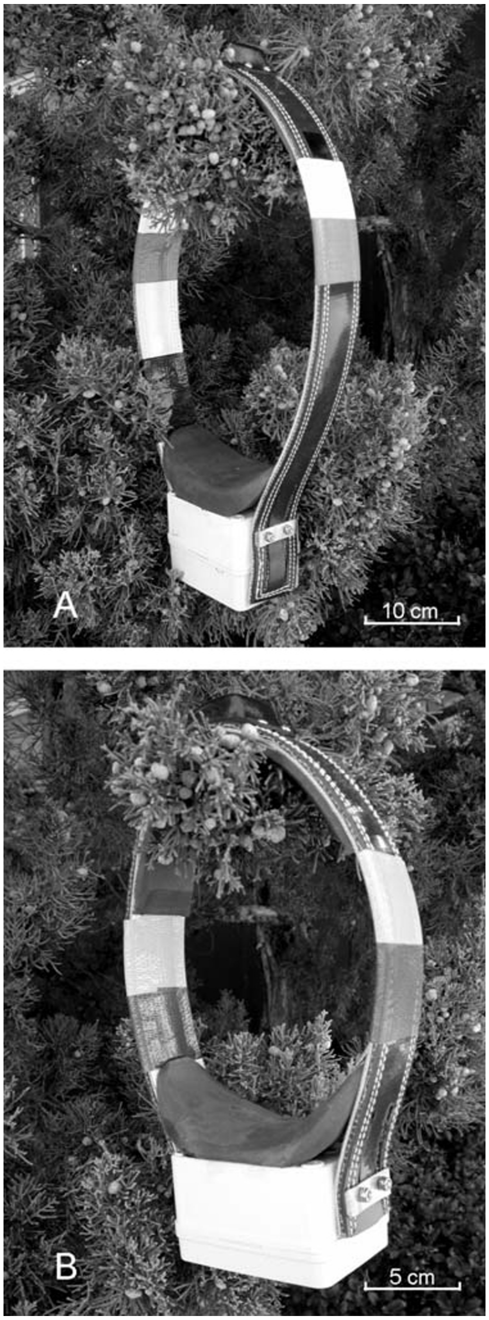

Figure 1. The Clark global positioning system Animal Tracking System collar, which can be sized to fit most livestock and large, terrestrial wildlife species, including **A,** Cattle and elk (990 g), and **B,** domestic or wild sheep, goats, deer, and wolves (720 g). The sheep/wolf-sized collars use shorter belting lengths and a smaller enclosure (box) to reduce bulk and weight.

Figure 2. The Clark global positioning system Animal Tracking System hand-held base station including personal digital assistant, spread-spectrum radio transceiver, and waterproof case.

Details concerning the Clark ATS are also presented at the website associated with this paper: http://clark.nwrc.ars.usda.gov/collars/index.php. Plans and instructions for constructing the Clark ATS are available from the corresponding author upon request.

Collar Components

Major components of the GPS telemetry collar include a single-board computer with a CompactFlash memory-card slot, a GPS receiver, an active GPS patch antenna, a spread-spectrum radio transceiver, and an omnidirectional radio antenna (Table 1). The collar is powered by either 1 or 2 high-capacity, D-cell batteries, depending on the planned length of deployment and weight considerations. Other collar components include a printed circuit board (PCB), a back-up battery, a regulator, capacitors, resistors, and various electrical connectors. A bill of materials list for the components needed to construct the collar is available at the Clark ATS website mentioned above.

Hand-Held Base-Station Components

Major components of the hand-held, mobile base station include a Pocket-PC personal digital assistant (PDA), spread-spectrum radio transceiver, omnidirectional antenna, and waterproof PDA case (Fig. 2; Table 1). The radio transceiver and PDA components of the base station were each powered by separate rechargeable battery packs carried outside the PDA case in a belt pack or backpack. Other base-station components included a level-shifter, regulator, rocker switch, antenna-adapter cable, PDA synchronization/serial-adaptor cable, capacitors, and resistors. As with the collar, a bill of materials for the base station is listed at the Clark ATS website.

Collar Construction

What follows is a very general sequence of steps involved in assembling the electronic components and constructing hardware components of the collar. A very detailed, step-by-step set of instructions and illustrations for use in constructing the tracking collar can be accessed at the Clark ATS website. Nearly all of the electronic components of the collar are mounted and electrically connected via the PCB (Fig. 3). The location where each component should be mounted is marked with white silk-screening on the PCB. The soldering involved in mounting and connecting components is simple and can be accomplished by a person with little or no previous experience. The first step is to mount the GPS receiver, GPS antenna connector, and other components required to supply and regulate power and to communicate with the GPS. Power is then applied to the PCB to confirm the GPS is operating properly. The GPS functions, such as power-saving modes, may be configured at this time as well. Next, the single-board computer and other components providing backup power and serial communication to the computer are soldered to the PCB. A memory card containing the collar test program and parameter file (see Collar Programming section below) is then inserted in the Compact Flash card-slot of the single-board computer and power is applied to the PCB once again. Assuming the GPS antenna is connected and has a clear view of the sky, the GPS should collect GPS-fix information and transmit it to the single-board computer where the data are stored on the memory card. With power disconnected, the card can then be removed and its contents reviewed using a memory card reader to confirm proper function of both the GPS and single-board computer. Finally, the radio transceiver is soldered to the PCB. If it becomes necessary to remove the computer from the PCB (e.g., due to computer malfunction or damage), this operation requires desoldering of both the radio transceiver and the computer. Consequently, delaying mounting of the radio until the GPS and computer have been fully tested can save a lot of frustration. Once mounted, the radio is configured and tested for successful communication with a radio configured to act as a base station (see Base-Station Construction section below).

The electronic components of the collar are highly susceptible to damage by moisture and impact and must be housed in a tough, waterproof enclosure. A collar made of conveyor belting material is used to attach the enclosure and its contents to an animal during deployment. The following is a general list of steps for constructing and assembling the collar belting and

Table 1. Electronic, environmental, and physical parameter specifications for the major components included in the Clark global positioning system (GPS) Animal Tracking System (Clark ATS) collars and base stations.[1,2]

Component	Parameter	Specification	Notes
Computer	Voltage, power supply	3.3 V	Single-board
	Power consumption, max.	412 mW	CompactFlash write
	Power consumption, suspend	20 μW	Suspend mode
	Temperature range	−40° to 85°C	—
	Interface, RS-232	1 channel	115 200 baud max.
	Interface, UART serial	7 channels	115 200 baud max.
	Memory, nonvolatile	1 MB	Flash memory
	Size, physical dimensions	35.5 × 63.5 × 17.8 mm	W, L, and H
GPS receiver	Voltage, power supply	3.0 V	16-channel receiver
	Power consumption, max.	375 mW	—
	Temperature range	−40° to 85°C	—
	Interface, UART serial	2 channels	115 200 baud max.
	Fix acquisition time	< 3.5 s	Hot-start mode
	Accuracy, horizontal[3]	6.3 m	95% CEP[4]
	Size, physical dimensions	25.4 × 25.4 × 3.0 mm	W, L, and H
GPS antenna	Voltage, power supply	3.0 V	Active antenna
	Power consumption, max.	63 mW	—
	Amplifier gain	27 dB	—
	Size, physical dimensions	40.0 × 48.0 × 13.0 mm	W, L, and H
Radio transceiver	Voltage, power supply	3.3 V	Spread spectrum
	Power consumption, max.	743 mW	—
	Temperature range	−40° to 80°C	—
	Interface, UART serial	1 channel	115 200 baud max.
	Transmission range	< 24 km	Line of sight
	Size, physical dimensions	41.9 × 48.1 × 5.1 mm	W, L, and H
Radio, antenna	Gain	2.14 dBi	—
	Size, physical dimensions	20.0 × 137.0 × 1.0 mm	W, L, and H
Battery	Voltage	3.6 V	D-cell
	Capacity[5]	19 AH	—
	Size, physical dimensions	35.0 × 62.5 mm	Diam and H

[1]Bill of materials lists and detailed instructions for constructing the Clark ATS collars and base stations can be acquired from the corresponding author or can be downloaded from the following website: http://clark.nwrc.ars.usda.gov/collars/.

[2]Max indicates maximum; UART, universal asynchronous receiver/transmitter; MB, megabyte; W, width; L, length; H, height; CEP, circular error probability; dB, decibel; dBi, gain in decibels referenced to an isotropic radiator; AH, ampere hours; and diam, diameter.

[3]Calculated using uncorrected (non–wide-area augmentation system) location data collected by GPS receivers contained within 5 deployment-ready Clark ATS collars.

[4]CEP is the radius of a circle (horizontal) that is centered at the GPS antenna's true position, and contains 95% of the GPS locations.

[5]Actual battery capacity depends on the resistance load, current demand, and minimum voltage-level requirements of the application.

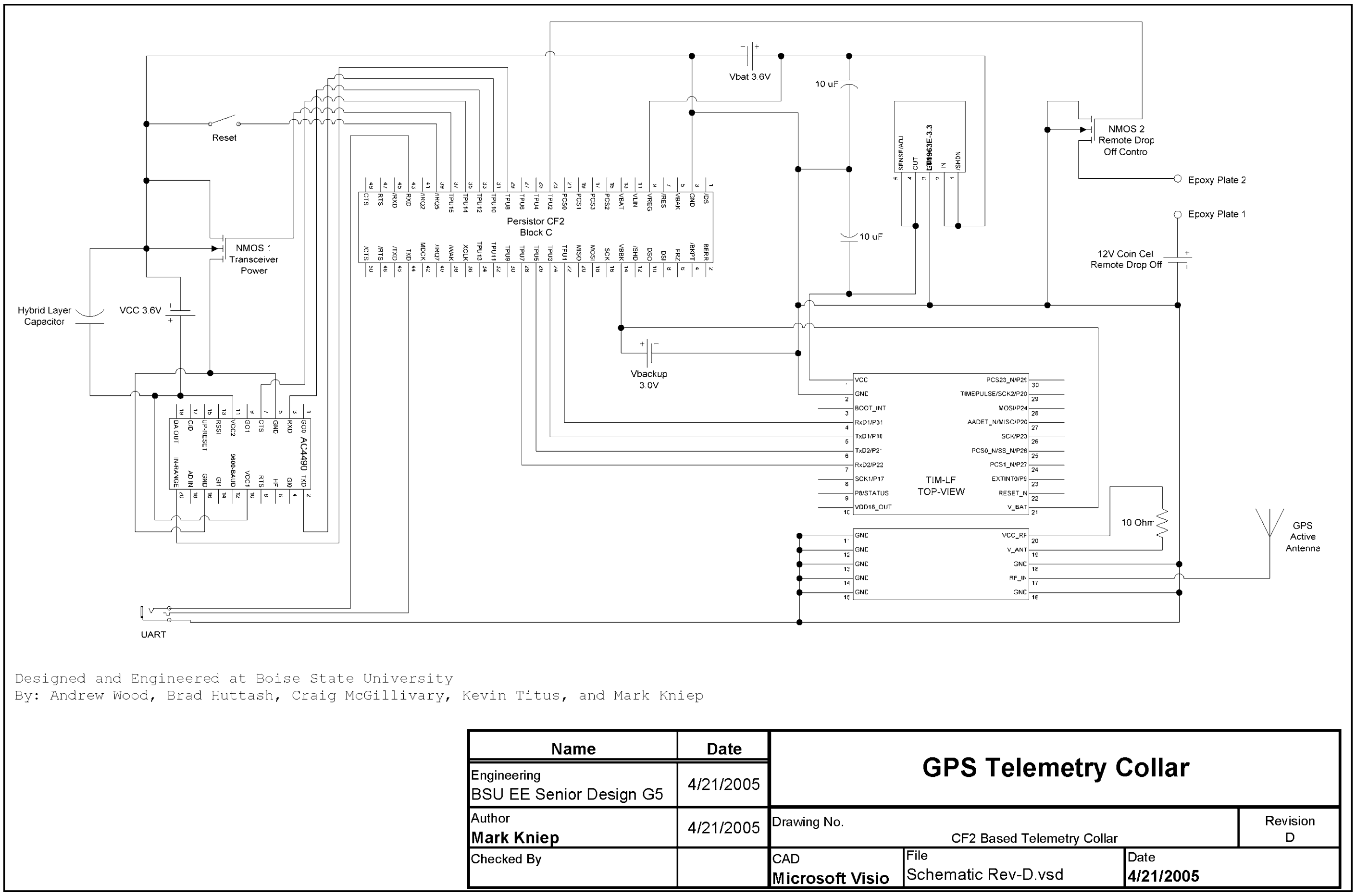

Figure 3. Schematic illustrating the placement and electrical connections for all the electronic components of the Clark global positioning system Animal Tracking System collar.

enclosure. First, 2 equal lengths of conveyor belting are laminated together with a double-row of stitching around the edge of the belting. Lengths of the belting will differ depending on the neck circumference of the animal species of interest (Figs. 1A and 1B). Next, neck size–adjustment slots or holes are cut into the belting. The GPS and radio antennas and cables are then threaded between the 2 layers of belting. The belting is attached to the sides of the enclosure using mounting brackets. The GPS and radio antenna cables ends are then inserted through a cable gland in the wall of the enclosure and plugged into their respective connectors on the PCB. Finally, a battery pack consisting of 2 D-cell batteries and associated capacitors is secured to the inside of the enclosure lid with silicon adhesive. Before testing or deploying the collar, the power cable from the battery pack must be connected to the PCB, and the enclosure is then closed and sealed. A bill of materials and detailed instructions needed for constructing the collar belting and enclosure are available on the system website.

Base-Station Construction

As with the collar construction, a detailed set of instructions for constructing the hand-held base station is available at the Clark ATS website. The following is a general description of how the electronics and hardware of the base station are constructed and assembled. First, the radio transceiver is configured to operate as a base station (i.e., a server). The radio and other components and wiring used to power the system and translate the serial output of the radio are mounted on a small PCB. The PCB and its wiring harness are then secured inside the waterproof PDA case. Finally, the PDA is secured inside the PDA case, connected to the PCB via the wiring harness, and the case is then closed and sealed. During deployment, the radio antenna and the power supply cables for the radio and PDA are connected to the base-station PCB via waterproof, bulkhead connectors passing through the wall of the PDA case (Fig. 2).

Collar Programming

The duty cycle or timing of operations for all major components of the tracking collar is controlled by a program placed in the nonvolatile memory (1 megabyte [MB]) of the single-board computer. This program uses a text file of control parameters, which is edited by the user and loaded on the collar's memory card before deployment. Parameters in this text file specify the date/time when the program should initiate data collection thus allowing collar deployments with a delayed start. The text file also directs the program in how often GPS data should be collected and how frequently information for the most recent GPS fix (i.e., a GPS-location beacon) should be transmitted by the radio transceiver to the base station. Data included in these radio transmissions are labeled with a collar identification value defined by the user as a parameter in the text file. Finally, when directed by radio queries from the base station, the collar program allows the user to remotely download data from the collar and remotely upload new programming. The collar program, source code, and an example of the parameter text file are available for downloading at the Clark ATS website.

Base-Station Programming

There are 3 software programs used by the hand-held base station. The first program receives incoming GPS-location beacon transmissions and stores these data in a database on the PDA of the base station. Incoming GPS-location beacon data are plotted in real-time on digital topographic maps or orthophotographic images using the second program. The third program allows the base station to send queries to collars requesting their stored GPS data. This program allows the user to remotely install new programming on a collar's computer. All 3 base-station programs, their source code, and instructions for their installation and use are available for downloading at the system website.

Collar Testing

The horizontal error or circular error probability (CEP) of GPS location data collected by the Clark ATS collars was evaluated using 4 collars placed, equidistant from each other, at 1 m in height, around the circumference of a circle that had a radius of 5 m and was centered over a geodetic survey point (point identifier = OH1352; NGS 1992). The collars were configured to collect data at 1-minute intervals and were deployed for 21 days, thus yielding more than 29 000 locations per collar. A 95% CEP value for each collar was determined by finding the radius of a circle that was centered over the true location of the collar (i.e., as determined by a 5-m offset from the geodetic survey point location) and which contained 95% of the locations. A mean 95% CEP was calculated based on the CEP values from all 4 collars.

Range-testing of the radio transceivers in the Clark ATS was conducted using 4 collars and 2 base stations. Of the 4 test collars, 2 collars were built with the radio antenna entirely enclosed between the layers of collar belting, whereas the remaining 2 collars were built with the antenna fully extended outside of the collar belting. These 2-antenna configurations allowed testing of collar belt effects on radio-transmission range. During testing, the base stations were established on an open ridgetop where a clear, line-of-sight distance of 24 km was available. Only 1 base station was operated at any one time to avoid interference problems. The test collars were transported away from the base station in a vehicle and were periodically removed from the vehicle and allowed to attempt to transmit their GPS location data to the base station from increasingly longer distances. Once a maximum distance for successful data transmission was reached using 1 base station, the second base station was employed to confirm these findings.

Battery life under intensive, short-duration collar deployments was tested using 5 Clark ATS collars deployed on beef cattle. The collars were configured to collect and store GPS data at 1-minute intervals and to attempt to transmit the most current location data every 15 minutes. The collars were deployed on mature cows that were using a high-elevation (< 2 438 m), sagebrush-steppe rangeland in central Idaho during July–August 2005. The collars were recovered in September 2005, data were downloaded, and the battery life for each collar was determined by contrasting the start date-time and end date-time (i.e., battery exhaustion date-time) values within the data record.

RESULTS AND DISCUSSION

The Clark GPS Animal Tracking System includes GPS-based tracking collars and a hand-held, mobile base station. Major components of the tracking collars include a single-board computer with a memory-card slot (CompactFlash), a 16-channel GPS receiver, and a spread-spectrum radio transceiver. All these components are mounted and electrically connected on a single PCB. These collar electronics are then contained within a watertight housing, which is mounted on a collar that can be sized for different livestock or wildlife species. The tracking collar collects and stores time-stamped data for the geographic location of the collar, which can be downloaded to a distant base station using the radio transceiver.

At this writing, the cost for a Clark ATS collar was about $840, excluding costs for about 2 hours of labor required for construction. Commercial GPS tracking collars with remote data–access capabilities typically cost about 3 to 4 times more per collar than the Clark ATS collar. This cost-savings allows the user to substantially increase the sample size and statistical power available in the experimental design of animal ethology and ecology studies.

The software programming capabilities available within the single-board computer of the Clark ATS collar allow the user to implement complex duty-cycle/power-management schedules (such as altering the data-collection rate in response to animal-activity levels). The computer also facilitates future integration and control of other sensor technology (e.g., accelerometers, digital cameras, microphones, or pulse oximeters and other animal physiology sensors) within the Clark ATS collar.

The 16-channel GPS receiver allows the Clark ATS collar to take full advantage of all GPS satellites in view at any one time (i.e., 1 to 12 satellites), while still leaving at least 4 channels open for other functions, such as acquiring WAAS data for real-time, differential-correction of collar location data. Field testing indicated the mean 95% CEP for uncorrected GPS location data collected with Clark ATS collars was 6.3 m (Table 1). Clark ATS collars collecting WAAS-corrected data yielded a mean 95% CEP of 2.7 m.

The spread-spectrum radio transceiver in the Clark ATS collar has several advantages over track systems using GSM cellular telephone, satellite, or narrow-band telemetry radio frequencies for telemetering data between collars and base stations. Currently, GSM cellular telephone coverage is very limited in the wildlands of North America and other regions of the world. Tracking systems relying on GSM service, consequently, have very limited utility for rangelands and other wildland applications. Use of commercial satellite communications is expensive and may have very restrictive data-throughput levels (e.g., 32 bytes per transmission). A tracking system relying on Service Argos for data retrieval would incur a cost of about $140 per month per collar transmitter for a typical deployment (Service Argos 2005). This service package would, however, only include 2 data-transmission time slots per day with a maximum of 32 bytes of data per transmission. Tracking systems using narrow-band radios operate on frequencies reserved by the Federal Communications Commission (FCC) for wildlife telemetry. Users of these tracking systems must obtain a narrow-band frequency allocation for each radio before deployment. These frequency allocations are often time-consuming to acquire and limit radio use to specific study areas with finite study duration. The FCC has authorized spread-spectrum radio transceivers to operate throughout the 902–928 MHz bandwidth; thus frequency allocations are not required. With spread-spectrum technology, a base-station radio transceiver (Server) and a collar radio transceiver (Client) must correctly identify each other and coordinate communication while hopping between frequencies. These requirements not only ensure successful data transmission despite heavy radio traffic and electronically noisy environments but also essentially encrypt and protect the transmitted data from unauthorized access.

Range-testing of spread-spectrum radio transceivers contained in the Clark ATS revealed that collars built with the radio antenna fully extended outside of the collar belting were capable of successfully transmitting GPS location data packets to a base station over 24 km away (line-of-sight). Collars with the antenna fully enclosed between the 2 layers of the collar belting were capable of successful transmissions out to 8 km. In cases where it is critical to enclose the antenna within the collar belting to prevent antenna damage, such as in predator-tracking applications, the user should expect a similar reduction in transmission range.

The memory-card data storage used in the Clark ATS collars provides a large increase in capacity over commercially available GPS-tracking collars, which typically can store no more than 10 000 differentially correctable collar locations. At this writing, the capacity of CompactFlash cards ranged from 16 MB to 8 gigabytes (GB). In the Clark ATS, a 64-MB card is capable of storing about 124 872 GPS locations (postdifferentially correctable) or the equivalent of about 88 days of data collected at 1-minute intervals. About 2 years of 30-second data could be collected using a 1-GB card.

The Clark ATS collars have a relatively high battery-life expectancy because they are constructed using components with very low power requirements (see Table 1) and are powered with high-capacity batteries. Battery life under intensive collar deployments was tested using Clark ATS collars deployed on beef cattle. Collars configured to collect and store GPS location data at 1-minute intervals exhausted the useable capacity (11 842 mAH) of the battery (3.6 V) powering the single-board computer and GPS receiver after about 24 days (563.4 hours), thus yielding a mean, overall power consumption of 76.5 mW. Despite this relatively low power consumption, however, battery-life expectancy tends to be the most limiting factor affecting how long the Clark ATS can be successfully deployed.

MANAGEMENT IMPLICATIONS

The objective of this research to develop a GPS-based animal tracking system (Clark ATS), costing less than $1 000 per unit, with spread-spectrum radio frequency communication between collar and base station, real-time collar tracking capabilities, large (up to 8 GB) user-expandable on-board data storage, and very low power demand (mean consumption < 100 mW) and with very high battery capacity (19 AH D-cells) was successfully met. These attributes and capabilities of the Clark ATS should allow the user to economically deploy the system on an adequate sample of animals for up to 3 weeks at a data capture rate of once every minute without the need to re-collect and service the collar. For longer-term deployments, the user could configure the system to acquire data at 15-minute intervals for up to 1 year without service. The real-time tracking capabilities of the Clark ATS should enable researchers to accurately examine animal distribution and activity responses to acute, short-term disturbances relative to longer-term behavioral patterns. Real-time GPS tracking may also provide time- and cost-savings to researchers and natural resource managers attempting to relocate a tagged animal in the field for direct observation or other operations.

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