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TELEMETRY MONITORING OF ECOLOGICAL RESOURCES

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Abstract

Current status of telemetry and location monitoring are discussed. Limitations on weight, communication range and service life are indicated. A general description of attachment methods and their limitations is given. Three automatic tracking system options are described. Several data recording methods are available including paper recorders and data recording using microprocessors with semiconductor memory. Satellite monitoring using the Argos/Tiros system and satellite transmission of data are also covered.

Résumé

L'état actuel de la télémétrie et du contrôle des positions fait l'objet d'une discussion. Les limitations concernant le poids, la portée de la communication et la longévité sont indiquées. Une description générale des méthodes de fixation et de leurs limites est donnée. Trois options de systèmes de tracking automatiques sont décrites. Plusieurs méthodes d'enregistrement de données sont disponibles, notamment des enregistreurs sur bande et des enregistrements de données utilisant des microprocesseurs avec une mémoire à semi-conducteurs. Le contrôle par satellite utilisant le système Argos/Tiros et la transmission des données par satellite sont également discutés.

Resumen

Se trata el estado actual de la telemetría y el control de la ubicación. Se indican las limitaciones en cuanto a peso, distancia de comunicación y tiempo de vida útil. Se da una descripción general de los métodos de fijación y sus limitaciones. Se describen tres opciones para un sistema de localización automática. Se dispone de varios métodos de registro de datos, incluyendo los registradores de papel y el registro de datos usando microprocesadores con memoria de semiconductores. Se cubre también el control por satélite usando el sistema Argos/Tiros y la transmisión de datos por satélite.

Резюме

Обсуждается современное состояние телеметрического и локационного мониторинга. Указываются ограничения веса, дальности связи и срока службы аппаратуры. Дается общее описание способов ввода в эксплуатацию такой аппаратуры и их ограничений. Дается описание трех различных систем автоматического слежения. Имеется несколько методов регистрации данных, включая пишущие регистраторы и регистрацию данных с использованием микропроцессоров с памятью на полупроводниках. Охвачены также мониторинг со спутников с использованием системы Argos/Tiros и передача данных по системе спутниковой связи.

TELEMETERY MONITORING OF ECOLOGICAL RESOURCES

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Since the introduction of the commercial transistor in the late 1950s, the application of electronics to the monitoring of biological parameters in wildlife has steadily progressed. Although some early remote sensing was done using subminiature electronic tubes, the first widespread application was location monitoring of animals in the mid 1960s. Monitoring activity has steadily increased since that time with an increase in numbers and types of parameters monitored. Today measurements can also be made using satellites to directly monitor or relay data. Progress is also being made in storing telemetered data for later retrieval and analysis. This paper discusses those recent advances with emphasis on possibilities for application to remote sensing of marine resources.

Radio Location Tags

The most prevalent use of radio tracking is the application where a radio marker beacon is attached to an animal and the animal then relocated using a directional antenna and receiver[2]. Data are usually recorded manually on paper by the observer. These data are then usually entered into a computer for data analysis. Some users enter their data directly into battery powered portable computers for later off-loading to a larger computer for data analysis. This technique eliminates the step of transferring data from paper to a computer. Error checks may also be included in the portable computer program to allow the observer to immediately recheck a data point in the field if a possible error is indicated.

Transmitters used in these applications are available in a wide range of sizes and power levels. There is a general correlation between transmission range, transmission life and weight. This correlation is determined by the energy source, with the most common energy source being a lithium primary cell. These cells have a high energy to weight ratio, excellent shelf life and perform quite well at low temperatures. They are the power source of choice in most applications. They are, however, not available in sizes below about four grams. Large sizes can also present transportation problems because of the classification of their lithium metal anode as a hazardous material.

Solar powered transmitters are also used[3]. Transmitters may depend on solar power only or may have a nickel cadmium rechargeable battery as power backup for periods when the sun is not in view. Unfortunately present designs have not given consistent performance from the solar powered nickel cadmium combination[4]. Mercury or silver-oxide cells are used in most of the small transmitters. Other than degradation of output at low temperatures, their performance is adequate for the application.

To save power, transmitters are usually turned on and off at a set rate. A typical rate is to turn the transmitter on for about 0.015 seconds once each second. This results in a duty cycle of 1.5 percent. Average battery drain is in the range of 0.15 to 0.6 milliamperes, with peak drains of about 10 milliamperes. Transmission life ranges from 45 days for a 2.5 gram transmitter to more than 1500 days for a 600 gram transmitter.

Reception range for these transmitters is quite variable. Small sizes range from 0.5 Km to 2 Km transmission range. For an observer in an aircraft, ranges are about two to five times greater. Transmitters on larger animals range from 5 to 10 Km on the ground and 10 to 100 Km from an aircraft. Transmission range is highly dependent on the transmitter's elevation above ground and on the length of the transmitter antenna. Longer antenna lengths provide higher efficiency and thus greater range. Since transmission for these low-power devices is line-of-sight, elevation of both the transmitter and receiver antenna above ground is also important. Thus a bird in the air will have a much greater transmission range than one on the ground.

Additional parameters can be measured using these transmitters by the addition of suitable sensors which modulate the pulse width, pulse rate or other characteristic of the transmitter[5]. The most commonly used sensor is a mercury switch which is a small glass tube with a ball of mercury that opens and closes an electrical circuit depending on the tilt angle of the tube. This can then be used to indicate activity by increasing the pulse rate as a function of switch closure. Mercury switches are also used to indicate mortality. In this case a clock is reset with each switch closure. If the animal is not active the clock will not be reset and the clock sends an output after a pre-set time, typically four hours. This output then changes the pulse rate, most commonly by a factor of two.

Temperature is also readily indicated by changing the pulse rate as a function of temperature. Pressure may be indicated in a similar manner[6]. These parameters can be measured quite easily because they change slowly with time.

Measurement of physiological parameters is somewhat more difficult because a decision must be made as to what constitutes a valid event[7,8]. In measuring heart rate - the most commonly measured physiological parameter besides temperature - a determination must be made as to what level to trigger the transmitter pulse. If the threshold is too high, heart beats will be missed, if too low, muscle artefacts will cause false indications. Trigger levels of 0.2 millivolts to 0.7 millivolts are used. We use a trigger level of 0.6 millivolts and try to place our electrodes for an electrode potential of 1.5 millivolts ideal, with 1.0 millivolts minimum. Telemetering of other physiological parameters under field conditions is less common. Procuring or developing adequate sensors is the major limitation in making long-term measurements under field conditions. Many sensors require periodic recalibration to assure accuracy and thus are not adaptable to long-term unattended use.

Transmitter attachment is a highly variable field with almost as many attachment methods as applications. Neck collars are the primary mode of attachment for terrestrial mammals. This technique elevates the collar well and provides good weight distribution. Other methods must be used in growing animals or in animals whose necks enlarge during the breeding season[9].

Back-mounted transmitters are the most commonly used attachment method in birds[10]. This technique provides the best distribution of weight to lessen the transmitter's effect on flight dynamics[11]. Transmitters are usually retained in position using a harness of flexible material. Adhesives are also used on birds for short-term applications. Usual life of adhesive attachment on birds is about 30 days when they are lost by feather breakage or molt. Clipping the transmitter to the tail feathers is also an option.

Attachment to marine mammals is often more difficult. If a suitable appendage is available a collar type attachment works well[12]. On animals with hair or fur, adhesive attachments have performed satisfactorily[13]. In any case the package should be small to reduce drag. Packages attached with adhesive will be lost during the animals molt and thus have a useful life of a year or less. Successful attachment to whales has remained a problem. Harpoon methods[14] and barnacle or multiple attachment[15] methods seem most promising.

Implanting the entire transmitter is also an option. It has been used successfully on sea otter[16], river otter[17] and ducks[18] as examples. The major disadvantage is the requirement of a surgical procedure and the reduction in transmission range caused by the body. Range for an implanted transmitter is typically 30 percent of the range which would be received from a transmitter attached externally. Antennas for implantable transmitters are either entirely enclosed within the package, usually as a helix at one end, or a whip external to the main transmitter package. The latter gives higher power output; however, the transmitter must be retained in place or the antenna will tend to form into a ball and become ineffective. Transmitters with integral antennas are usually allowed to "float" either subcutaneously or interperitoneally. In sea otters interperitoneal placement is more successful because it does not leave a lump and the surgical would heals faster[19]. Generally the attenuation of the radio signal is a function of the thickness of the body tissue in the signal's path.

Automatic Tracking Systems

Several systems exist to automatically track the location of animals as they move within the area monitored. The first of these was a system developed at the University of Minnesota in the mid-1960s[20]. It used two mechanically rotating antenna arrays. Originally data were recorded on 16 millimeter film although later a computer was used to determine the angular bearings. A similar system was built at the University of Bordeaux, France[21]. These systems have limited application in Antarctic environments because of their limited portability, high power requirements for the mechanical antenna rotation and the level of technical support needed for successful operation.

A more recent system is one presented by Tracktech AB, of Salna, Sweden. It uses a hyperbolic direction-finding technique which does not need rotating towers. Three systems are claimed to have been sold, but no reports are available on their performance. While this system does not require rotating antennas it requires technically complex receivers and transmitters. Cost for a basic Tracktech system is about US$100 000.00.

A third approach is provided by a system measuring the doppler shift of a signal using an array of antennas which are rotated electronically. Transmitters on the animals have no special requirements. This system offers possibility as a remote, portable tracking station because it does not have rotating towers, has relatively low power requirements and should be able to operate without complex technical support. Although several doppler system are under development, I was not able to get either company to consent to releasing information.

Data Recording

A number of methods and systems have been developed to record data from radio and sonic tags without the presence of an observer. These are usually relatively low cost portable systems.

The first system developed used a low cost analog chart paper recorder that recorded the signal level from the receiver[22]. The chart drives were either spring wound or electric motor driven. They can be used to indicate activity or transmitter proximity to a nest or other specific site. While these units perform well, they have limited application because they must be attended frequently to wind the spring driven motors or recharge the battery. Temperature variations have also been a problem. Power for the units is usually provided by an automobile storage battery. Rustrak and Esterline-Angus are two manufacturers of analog recorders for this application. These systems are usually used to monitor from one to four animals. Monitoring more than four transmitters is difficult because there is no easy way to distinguish the animals on the chart.

To meet the need to monitor more animals and eliminate the need to adjust the receiver gain control, systems based on event recorders were developed. Event recorders typically have 10 or 20 pens which are activated by a voltage signal. They give only a yes or no indication and provide no information on signal level. These systems are ideal for recording presence or absence data. To operate effectively with these event recorders the receivers should have a tone decoder or other level insensitive detection method. The recorders have spring wound drive motors which will operate the recorder for about one week. Receivers in this application are most often powered by automobile batteries.

As microprocessors became more familiar and solid state memory devices gained capacity and became less espensive, systems which store data from the receiver and can later off-load to a small computer are becoming available. These systems use the microprocessor to control the receiver, check the data, record time and data. It can also turn the receiver on and off if desired. Since the system has no moving parts it can operate over a wide temperature range.

Using receivers and a monitoring system developed at the University of Minnesota we have tested operation to -50 degress C without deterioration in operating performance. The model we currently use has a basic interpreter in read only memory so that it can easily be reprogrammed in the field. Speed sensitive operations can be written in assembly language and called from the main program as needed. Using the high level language permits the user to easily change the program or design it to fit his need as required. For our particular device communication to an external computer is done via a RS-232 serial interface. Using this standard interface any number of terminals can be used to communicate with the system and off-load data. Using this system and an adequate power source for the receiver, operation for several months without attention is possible.

Using a microprocessor enables the user to record additional data such as temperature, depth, heart rate or any parameter that can be put into digital form. A microprocessor also permits the user to specify limits which can be used to discard out of range data points.

Satellite tracking

Since the first elk was tracked by satellite in the early 1970s biologists and wildlife managers have been interested in applying this technology to biological monitoring. A number of experiments were conducted utilizing the Nimbus system. However, animal tracking using satellites began in earnest with the Argos system.

The Argos system offers opportunities for monitoring a large number of species. However, its operational characteristics and requirements must be understood if it is going to be used successfully. The system is designed to monitor the location of transmitters (often referred to as platforms) using a satellite in sun synchronous orbit. Some data can also be transmitted along with the information necessary for location. The system's primary design purpose is to monitor meterological sensors on balloons and ocean buoys; monitoring biological data was secondary.

Sun synchronous orbit means that the satellite remains in a fixed orbit in space. However, it covers a different path on the earth as the earth rotates relative to the satellite's orbit. The satellite orbits with a period of 102 minutes. This, combined with its polar orbit, means that points near the equator are in view less frequently than are points near the poles. It is designed to have platforms at the equator in view for at least two passes, whereas platforms nearer the poles will be in view with almost every pass.

The Argos system uses a doppler location technique. As the satellite gets closer to the platform the frequency appears to increase. As the satellite passes over the transmitter, the transmitter frequency appears to decrease. The measurement of the transmitter frequency can then be used to establish a doppler curve. Using the doppler information, the position of the transmitting platform can be determined to within two possible positions. On the next satellite orbit two additional possible positions are determined. One of these positions should coincide with a position from the previous pass. The doppler curve can only be determined accurately if a number of transmissions occur as the satellite passes overhead. This means the platform must transmit over this period. Since the platform transmits once each minute it should be available for at least five continuous minutes. This is not a problem for birds or terrestrial mammals. However, for many of the marine mammals it is a significant consideration.

Argos platforms must be certified by Service Argos before they can be placed in service. Approved platforms are available from a number of commercial sources (see Appendix A).

With the doppler measurement system the frequency of the transmitter must remain stable over time or errors in the doppler location will occur. Thus the transmitter oscillator must remain stable over time and with temperature variations. Another important parameter is the three watt power output requirement. In most cases power is supplied by lithium primary cells. Two problems must be considered : the first is the ability to supply the power for the operating life desired; the second is to have sufficient capacity to supply the peak demand during the transmission period. Both of these factors are increased by low temperatures.

These two factors determine the smallest size of transmitter that can be built. While some decrease in size can be made using custom circuits, very little can be done with the major volume component, the primary battery. Some testing has been done using solar cells and nickel-cadmium batteries. However, reliable operation for more than about nine months has not been achieved.

Currently transmitters weighing approximately two kg and lasting about one year are routinely being deployed on caribou[23], Antarctic seals and polar bear. Units have also been placed on a number of other species with varying degrees of success. A significant problem is attaching packages of this size and weight. Transmitters have been carried by several species of birds with mixed success. The users indicated the weight (170 gm) and bulk were too high[24]. Cost for location-only transmitters is in the 2500 to 3500 US$ range.

There is a service charge for data processing by Service Argos. Typical cost for a platform-year is about 3000 US$ (see Appendix B for a rate schedule). It is possible to bypass Service Argos data processing and to use the down-link data to determine location with an on-site data processor. These data processors are also relatively expensive (20,000 to 30,000 US$) and require technical support.

The Argos system also allows the sending of four eight bit data words with each transmission. These can be used to send data such as temperature, pressure, etc. It should be noted, however, that doing so increases the demand on the power supply.

Satellite Transmission of Data

As an alternative to sending data to satellite, using the Argos system data can be relayed using other data-only satellite systems. Since they are data-only systems these systems permit the transmission of larger blocks of data. A data relay system using the GOES satellite is being tested by a National Marine Fisheries Laboratory. The application of this system is to monitor fish as they traverse remote streams and rivers. Radio frequency tags are attached to fish which are then monitored with a radio receiver and data processor. Data from the receiver data processor are sent to the GOES transmitter once per hour for relaying to the GOES satellite. The GOES system allows sending up to 650 characters per transmission. This application uses commercially available GOES platforms. Data are downlinked to a receiving station at Wallops Island, Virginia where they are available to the user. Power for this system is supplied by solar cells recharging Gel-cell batteries.

Acoustic Tags

Acoustic tags are applied most often in high conductivity or deep water where radio frequency tags will not function. These tags emit a mechanical wave in the frequency range 25 to 200 kHz. The sound energy is received by a hydrophone and a narrow band receiver which separates the signal from the noise. After the signal is received it may be processed using the same methods as described for radio frequency tags.

Tracking range for acoustic tags is dependent on power output and frequency. Signal attenuation increases as frequency increases because absorption loss is frequency dependent. These losses are in addition to spreading losses. Thus using lower frequency transmitters will result in a longer range. Using a lower frequency may cause a problem, however, if the tag frequency is within the hearing range of the animal. Tag size is also frequency dependent because it is desirable to operate the acoustic transducer near its resonant frequency. Transducer resonant frequency is size dependent; efficient low frequency transducers require a large size. Thus it is difficult to build a small low frequency device[25].

Passive Acoustic Sensing

It is possible to monitor objects in ocean environments which are too small for transmitter attachment by transmitting an acoustic signal and measuring the level of reflected signal. These systems use relatively high frequencies and are normally ship mounted. Using these systems it is possible to monitor fish, krill and zooplankton. Assessments of stocks using these techniques is in its preliminary stages[26]. Assessment of biomass is not particularly difficult. However, determination of the organism causing the signal return may prove to be more elusive without concurrent sampling.

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APPENDIX A - PRODUCERS OF CERTIFIED PTTS

Source : ARGOS Newsletter (December 1986)

Bristol Aerospace Limited, PO Box 874, Winnipeg, Manitoba, R3C 2S4, Canada

Ceis Espace, Z.I. de Thibault, 31084 Toulouse Cedex, France

Eidsvoll Electronics, PO Box 38, N. 2081 Eidsvoll, Norway

Ferranti O.R.E. Inc., PO Box 709, Falmouth, MA 02541, USA

Hermes Electronics Limited, 40 Atlantic Street, PO Box 1005, Dartmouth, Nova Scotia B2Y 4A1, Canada

Instituto de Pesquisas Espacias, c.p. 515, 12200 Sao Jose dos Campos - SP, Brazil

Mariner Radar, Bridleway - Campsheath, Lowestoft, Suffolk, NR32 5DN, Great Britain

Metocean Data System Limited, PO Box 2427 D.E.P.S., Dartmouth, Novia Scotia, Canada

Polar Research Laboratory, Inc., 6309 Carpinteria Avenue, Carpinteria, CA 93193, USA

Synergetics International, Inc., 6565 Odell Place, PO Box E, Boulder, Colorado, 80306-1236, USA

Telonics, Inc., 932E. Impala Avenue, Mesa, AZ 85204, USA

Toyo Communication Equipment Co Ltd., 753, Koyato Samukawa-Machi, Koza-Gun, Kanagawa-Pref Code 253-01, Japan

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APPENDIX B

1986 TARIFF

(all prices in French francs and exclusive of taxes)

TARIFF CODE	ITEM		PRICE (FF)
A 10	STANDARD SERVICE, PTT rp < 60 s	*(per PTT and per day)*	191.10
A 11	surcharge for more than 6 loc. calcul.	*(per PTT and per day)*	9.55
A 20	STANDARD SERVICE, PTT rp > 100 s	*(per PTT and per day)*	25.50
A 21	surcharge for more than 10 data acquis.	*(per PTT and per day)*	1.25
A 30	BACK-UP SERVICE, PTT rp<60 s	*(per PTT and per day)*	38.20
A 31	surcharge for more than 6 loc. calcul.	*(per PTT and per day)*	1.90
A 40	BACK-UP SERVICE, PTT rp>100 s	*(per PTT and per day)*	12.75
A 41	surcharge for more than 10 data acquis.	*(per PTT and per day)*	0.65
A 50	MONITORING SERVICE, PTT rp < 60 s	*(per PTT and per day)*	23.90
A 60	MONITORING SERVICE, PTT rp > 100 s	*(per PTT and per day)*	10.05
B 10	DATA RECORDED ON TAPE, PER 1200 FT (EUROPE)	*(per unit)*	580.00
B 11	" " " " " " " (OTHER ZONES)	*(per unit)*	714.00
B 20	" " " " PER 2400 FT, (EUROPE)	*(per unit)*	777.00
B 21	" " " " " " " (OTHER ZONES)	*(per unit)*	903.00
B 30	PRINTOUT, PER 50 pp (EUROPE)		121.00
B 31	" " " " (OTHER ZONES)		147.00
C 10	SURCHARGE FOR RETROACTIVE COPYING	*(per month)*	693.00
C 20	MODIFICATION	*(per intervention)*	200.00
D 10	PTT HIRE, INCLUDING A10 SERVICE, 45 DAYS		15,225.00
D 11	PTT HIRE, WITHOUT PROCESSING, 45 DAYS		6,720.00
D 20	PTT HIRE, INCLUDING A10 SERVICE, 90 DAYS		26,145.00
D 21	PTT HIRE, WITHOUT PROCESSING, 90 DAYS		9,135.00
D 30	PTT HIRE, INCLUDING A10 SERVICE, 135 DAYS		37,590.00
D 31	PTT HIRE, WITHOUT PROCESSING, 135 DAYS		12,075.00
D 40	PTT HIRE, INCLUDING A10 SERVICE, 180 DAYS		47,985.00
D 41	PTT HIRE, WITHOUT PROCESSING, 180 DAYS		13,965.00
E 10	PROCEEDINGS OF USERS CONF. (EUROPE)	*(per document)*	231.00
E 11	" " " " (OTHER ZONES)	*(per document)*	294.00