Fifteen Years of Satellite Tracking Development and Application to Wildlife Research and Conservation

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A small satellite-based tracking system that is light enough to be carried on birds was developed in the 1980s at the Applied Physics Laboratory. A new, more capable generation is now under development that will contain, in addition to the Argos tracking platform transmitter terminal, a global positioning system receiver and a complement of advanced sensors. The sensors may include a digital audio capture system and a black-and-white charge-coupled device camera. The history of the program and plans for future development are discussed.

INTRODUCTION

Fifteen years ago, the U.S. Army initiated a program at APL to investigate the development of small platform transmitter terminals (PTTs) to be tracked by the French–U.S. Argos–Tiros satellite system.[1] Since the inception of the program, miniaturization has led to the fielding of transmitters that weigh less than 28 g and can interface with an array of sensors. Results of field tests during the late 1980s and early 1990s, examples of applications, and continued development of the technology are reported here.

In 1981, the Bird-Borne Program was initiated at APL to develop a capability to locate (i.e., track) and monitor small, highly mobile animals on a local, regional, and global scale. The primary objective of the Bird-Borne Program and the Remote Environmental Sensing Technology Program was to develop a satellite transmitter for the remote tracking and monitoring of free-ranging animals. Avian species were the focus because of their relatively small size and high mobility. Additional focus has been on birds of prey, which are top predators and scavengers that are widely dispersed and can move quickly over rugged, inaccessible terrain.

Conventional biotelemetry enables biologists to locate previously captured and radio-tagged animals. Biotelemetry also can be used to collect information from the environment surrounding the animal (temperature, humidity, and altitude) as well as behavioral and physiological parameters (motion, core temperature, and heart rate) of the animal.[2] Until biotelemetry became available, information on free-ranging animals was difficult to obtain. For many secretive animals it could only be inferred from meticulous indirect sampling methodologies. Biotelemetry has enabled scientists to accurately study behavior, home range, and habitat use of wildlife for basic research and the development of management plans for conservation.

Conventional biotelemetry systems often use directional receiving antennas to locate or triangulate transmitters. They are usually restricted to small geographic areas accessed on foot, by automobiles, or by aircraft.[2]

However, for studies of free-ranging animals that travel long distances over extended periods and frequent habitats that are inaccessible because of geographic or boundary restrictions such as military installations, space-based tracking and monitoring systems are advantageous. The study and conservation of migratory birds are topics to which the application of telemetry via satellites is especially useful.

Each year hundreds of thousands of birds representing many species cross dozens of geopolitical boundaries migrating from their North American breeding grounds to milder climates as far south as Central and South America. During migration, these birds stop to rest and feed in areas that provide resources to shelter them and fuel their flight. These areas are critical habitats for many species, and without continued management of the habitats, avifauna could be lost on a large scale. The problems inherent in the study of migrants represent major barriers to the effective management of these species, many of which are declining in numbers annually.[3] Remote tracking and monitoring systems can support effective study of these animals and aid in identifying their range and critical habitat requirements for breeding, migration, and wintering.

As a signatory to Partners in Flight, a program to study and conserve neotropical migrants, the Department of Defense contributes with comprehensive effort in environmental technology and conservation. The DoD is the third-largest land holder in the United States. It uses the lands for research and development; material test, evaluation, and production; and comprehensive training programs to maintain military readiness for national security. It has established requirements for environmental research, technology development, and land management and supports a variety of programs such as Legacy and the Strategic Environmental Research and Development Program to achieve excellence in natural resources management. The conventional collection of field data by scientists on free-ranging animals found within military installations often conflicts with the military mission and requires the temporary suspension of military activities because of their inherent hazards and classified aspects. Furthermore, biological studies designed to evaluate the effects of military land use on natural resources pose unique and difficult problems because biological data must be collected during military activities. Advanced technologies that allow remote tracking and monitoring of wildlife can alleviate many of these conflicts yet provide comprehensive data.

The Bird-Borne Program's effort to develop a space-based tracking and monitoring capability started with a study to evaluate the critical engineering paths to build a satellite transmitter for use on free-ranging birds. Requirements for the development of the first prototype satellite transmitter were (1) identify a space-based system for transmitter development, (2) develop a PTT weighing less than 200 g, (3) allow for 270 days of operation, and (4) accommodate environmental, behavioral, and physiological sensors on the PTT.[4]

The French-operated Argos system implemented in the 1970s proved to be the basis for the development of a bird-borne transmitter. The Argos system, dedicated to environmental monitoring, consists of receivers on the Tiros N series of National Oceanic and Atmospheric Administration satellites positioned in low (850-km) polar orbits. The Argos system and PTTs were being used to monitor and track atmospheric balloons and pelagic buoys to collect marine and meteorological data. The PTTs operated with primary batteries and weighed 1 kg or more. The location of PTTs is determined on the basis of Doppler shift, which is dependent on a highly stable frequency transmission at 401.6 MHz. Because the accuracy of the position is based on the stability of the signal frequency, all the available transmitters in the early 1980s had crystal oscillators that were maintained in constant-temperature ovens. The large power requirement for the operation of the heated crystal oscillator oven posed a serious technology barrier for the miniaturization of a bird-borne PTT.[4]

A bird-borne PTT had to be relatively small (<200 g) to avoid adversely affecting bird flight.[5,6] The Argos system required PTTs to transmit a minimum of 1.0 W. To meet this power requirement for transmission for 270 days required 500 g of primary batteries. This approach exceeded by more than a factor of 2 the maximum mass of the prototype bird-borne package. Therefore, we initially met the power requirement by using a solar array with rechargeable nickel–cadmium batteries. This power pack allowed for a duration of nearly 1000 recharging cycles, or nearly 3 years. The constant-temperature oven for the crystal oscillator was eliminated with the development of a temperature-compensated crystal oscillator, which was one of many innovative electronics designs produced by the Bird-Borne Program.[4] A 180-g prototype PTT was developed and field tested in 1983 on a mute swan captured on the Eastern Shore of Maryland. The mute swan carried the PTT aloft during the summer of 1983, and this test led to a series of additional field tests with other avian species.[7]

In the autumn of 1984, the APL bird-borne transmitter was placed on an endangered bald eagle captured on the Aberdeen peninsula in the northern Chesapeake Bay of Maryland. Bald eagles are common winter visitors on the Aberdeen Proving Ground (APG), and they are carefully managed by the U.S. Army. A winter roost for bald eagles, one of the largest in the lower 48 states, holding as many as 100 bald eagles, is located at

APG. The captured eagle was the focus of a study to examine the distribution of eagles on the military installation and examine their relation to military activities as well as to the surrounding land use in the northern Chesapeake Bay.[8] The eagle was equipped with the PTT, released, and tracked for 9 months.[7] The eagle initially moved north into Pennsylvania after visiting a critical roost and foraging area for many eagles along the Susquehanna River below the Conowingo Dam. During the course of the next 270 days, the eagle returned to its natal origin in South Carolina and then flew south through Atlanta, Georgia, to winter in St. Augustine, Florida. In the spring, the eagle began northward flights and then the transmitter lost power on the Georgia barrier islands. This eagle was found 5 years later (with the PPT intact), after it had been struck by a train. The first swan and eagle tracked with the prototype transmitters developed at APL provided valuable insight into the application of this technology to the study of large avian species. Subsequently, we tested and evaluated this technology on other bald eagles, swans, and giant petrels.[7,9,10]

TECHNOLOGY APPLICATION

Some of the first applications of PTTs to natural resources management issues were with golden eagles. In Canada, golden eagles had been selected as a species for a Hydro-Quebec project to evaluate the effect of flooding caused by a large hydroelectric dam south of James Bay, Ontario. Eagles from the affected area were tagged with PPTs and tracked south to their wintering grounds in the eastern United States. The golden eagles, tracked via satellites, distributed themselves over the entire known eastern U.S. wintering range for the species, thereby establishing the James Bay area as important for the maintenance of the species in eastern North America.[11,12]

In 1990, a comprehensive study was initiated on golden eagles for the Idaho Army National Guard in the Orchard Training Area south of Boise, Idaho. The Orchard Training Area is centrally located within the Snake River Birds of Prey National Conservation Area. In the Orchard Training Area, we examined the spatial relationships of military training to golden eagle movements. Telemetry through the Argos–Tiros satellites was required because eagles of unknown origin joined the resident birds (tagged with conventional transmitters) during the winter. The new arrivals were tagged with PTTs. Initial results of ongoing work have shown that some eagles use the military training area extensively to winter; most adult birds remain on the military area, whereas younger golden eagles use it less extensively and range widely (Fig. 1). Also, unique information on the breeding areas of the adult eagles was obtained within the first year of the study. Eagles that wintered in the Orchard Training Area were thought to come from breeding areas northwest of Boise, Idaho. During the spring of 1993, all the adult eagles tracked via satellite migrated to breeding locations in central Alaska and western Canada (Fig. 1). This new information is important for the development of natural resource management plans for the Idaho Army National Guard training program. During periods of high military training activity in the late spring and summer, a large component of golden eagles that use the area

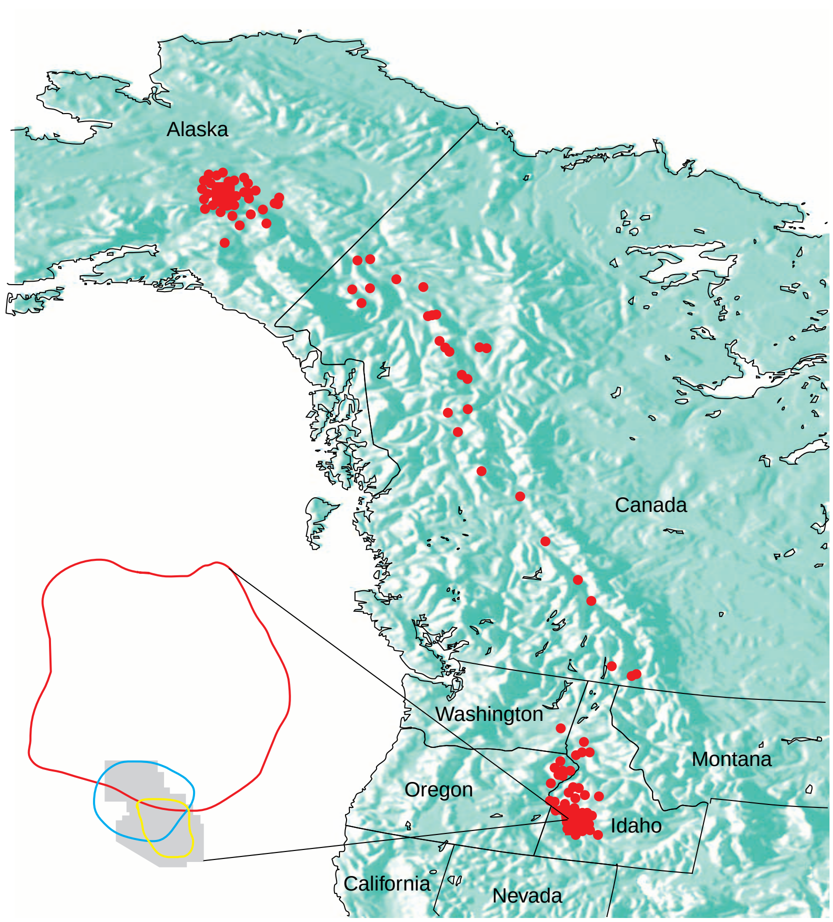

Figure 1. Inset shows the wintering home range of a subadult golden eagle (red circle) and two adult golden eagles (blue and yellow circles) overlayed on the boundary of the Idaho Army National Guard Orchard Training Area, located south of Boise, Idaho, in the Snake River Birds of Prey National Conservation Area. Large map shows the migration of wintering golden eagles to their breeding grounds in western Canada and Alaska.

annually in the winter is absent and thus not affected by training.

During the late 1980s and early 1990s, the application of tracking birds via satellite expanded because PTTs were miniaturized; thus, the number of species that could carry the PTT increased. Our use of radio tagging always has been based on careful consideration of the effects of the transmitters on birds' behavior and flight.[13–15] Since the early 1990s, over 500 PTTs have been deployed on more than 20 avian species on a global scale.[12] In the autumn of 1993, the first PTTs (NANO 100 Model, Microwave Telemetry, Inc.) weighing 27 g were attached to tundra peregrine falcons (Fig. 2), an endangered species and neotropical migrant that breeds as far north as the Arctic and winters primarily in Central and South America. During the following 24 months, 50 PTTs were deployed on peregrines in five locations in North America and one location in the western Russian Arctic. Results of this effort have been applied to our goal of describing the range of this endangered species and identifying critical breeding, migratory, and wintering areas for the conservation of peregrines.

With the assistance of Michael Yates, Thomas Maechtle, James Dayton, Linda Schueck, and other colleagues, we radio-tagged and tracked peregrines during the autumn in Maryland and Virginia on Assateague Island and along the Texas Gulf Coast on Padre Island. Also, we tagged adults on Padre Island in the spring as they moved out of Latin America, north to their Arctic breeding grounds. Padre Island, Texas, is the only known staging area for the tundra peregrine in the Northern Hemisphere and provides a critical migratory habitat for the species during northern flights. Some PTTs were programmed to operate for 12 months, transmitting for 8 hours every 3 days during migration and then switching to a 6-day cycle of transmission during breeding and wintering periods when the birds were more sedentary. During the breeding season of 1994, David Bird, Robert Johnstone, and others helped us place PTTs on adult females in Ungava Bay and Rankin Inlet, Canada. In Kangerlussauq, Greenland, with the support of William Mattox and the Greenland Peregrine Falcon Survey, and on the Kola Peninsula, Russia, with Sergi Ganusavich, we also marked breeding female peregrines. During the past 24 months, we have collected over 6000 positions for these peregrines. These data have provided more information on the species distribution in the Northern and Southern hemispheres than 25 years of conventional field studies and banding returns. The PTT-tagged peregrines from this sample of 50 wintered from Delaware to Argentina and returned to breeding grounds across the northern Arctic from Alaska to Greenland (Fig. 3).

The individual migratory paths of peregrines have been interesting. For example, peregrine no. 5707 (a female) was captured in the spring on Padre Island, Texas, and provided unique information about a wandering nonbreeding adult (Fig. 4). This falcon flew from the Texas Gulf Coast to the Rankin Inlet study area where nonbreeding peregrines are commonly seen by biologists studying this species (personal communication, R. John-stone, Nov 1995). She then left the western shore of Hudson Bay, traveled to southern Baffin Island, and went north to the Arctic Ocean. During fall migration, she traveled from northern Baffin Island, south by way of the eastern coastal flyway, to a wintering area along the northern coast of Venezuela. This information was collected and mapped on a computer, at a minimal cost of field time and expense. Furthermore, it provided regular data from a bird flying through areas that simply could not be effectively covered by conventional wildlife tracking methods.

Figure 2. Peregrine falcon with a platform transmitter terminal.

During the past 15 years, the electronics in the satellite transmitter have been continually miniaturized and have provided new capabilities through the integration of microprocessors and minicomputers (Fig. 5). The newest experimental bird-borne transmitter produced by Microwave Telemetry, Inc., weighs 20 g, which includes 3.5 g of electronics, an 8.0-g battery, and an

Figure 3. Arctic breeding locations (red circles) and wintering ground locations (blue squares) of tundra peregrine falcons as determined by satellite tracking.

8.5-g container. The transmitter can interface with a variety of sensors to collect information from the animal's environment as well as behavioral data. This technology is now being used to gather data and address questions and issues that were previously either impossible or too costly to consider with conventional methods. Many colleagues are now applying PTTs to the study of birds[12] as well as other wide-ranging animals.[16] We are combining satellite-based tracking technology with other technology and with innovative approaches to the research and management of natural resources.[17]

In the autumn of 1995, under the auspices of the DoD-sponsored Legacy Program called Satellite Tracking and Monitoring Threatened, Endangered and Neotropical Species, four Swainson's hawks were radiomarked for demonstration on the Orchard Training Area. These hawks were instrumented to track their movements over the Orchard Training Area and to demonstrate use of the Argos system with a geographic information system to remotely track and monitor sensitive species. A second phase of the demonstration revealed the migration path and wintering locations of the birds in South America. The Swainson's hawk is listed as a species of concern by five states and the Bureau of Land Management and as a special emphasis species by the U.S. Forest Service in some areas. Nesting population declines have been reported over much of the hawks' range, including Dugway Proving Grounds, although not in all areas. With no obvious reason for this decline, scientists postulated that problems along migration routes or in wintering areas were responsible. In 1994, two Swainson's hawks were equipped with PTTs as part of a pilot study to determine the winter destination of northern Californian Swainson's hawks. During a subsequent visit to a wintering site indicated by a satellite-tracked PTT, communal roosts were discovered in the Pampas area of Argentina, and over 700 recently killed hawks were documented adjacent to agricultural fields.[18]

An investigation began, and in 1995, biologists from federal, state, and local governments, as well as private institutions in the United States and Canada, teamed to track the destinations of 12 Swainson's hawks from Saskatchewan, Idaho, Utah, California, and Colorado. In January 1996, scientists visited different areas indicated by the satellite-derived location data, including the area visited in 1994. They counted over 4000 dead hawks, apparently killed by pesticide applications, and believe the actual mortality numbers exceeded 20,000. With adults representing nearly 90% of the dead birds and the entire Canadian Swainson's hawk population estimated to be between 20,000 and 40,000 pairs, this mortality estimate indicates a serious threat to the survival of the species.

This application of satellite tracking is a perfect demonstration of the unique advantage this technology can provide in the study of a wide-ranging species. As the technology evolves, future sensors for animal tracking units will include a capability to monitor chemicals in the animals' environment. Many research

Figure 4. Movements of a nonbreeding tundra peregrine falcon captured on Padre Island, Texas. Migration from Padre Island to Baffin Island in the spring of 1994 is shown as a broken line. Migration from Baffin Island to Venezuela in the fall of 1994 is shown as a solid line.

tagged animal is also discussed. Finally, we report on the integration of these sensors being developed at APL with a new generation of commercially available Global Positioning System (GPS)–equipped Argos PTTs for enhanced acquisition of accurate positioning data.

Digital Audio Capture and Control Circuit

Figure 6 is a block diagram of the entire electronics system of the digital audio capture and control circuit for monitoring behavioral noise. The design of the digital audio capture circuit centers on an 8-bit microcontroller. This device was chosen because it has several system components on a single chip, and small size and weight are critical in this system's design. The subsystems of the microcontroller are the internal universal asynchronous receiver transmitter (UART), internal timer, internal random-access memory (RAM), electrically erasable programmable read-only memory (EEPROM), and 8-bit analog-to-digital converter. The analog-to-digital converter is used to sample the amplified signal from

questions remain, however, and important conservation issues need to be addressed in a timely, effective manner. Both issues would benefit from additional development of the technology.

CURRENT TECHNOLOGY DEVELOPMENT

In this section we discuss the development of a bird-borne transmitter that will incorporate a behavioral noise monitor to assist in the interpretation of acoustical information to link time and location to discrete animal behaviors. The feasibility of integrating a miniature camera with the new generation of bird-borne transmitters for the collection of pictorial data pertinent to the habitat surrounding the radio-

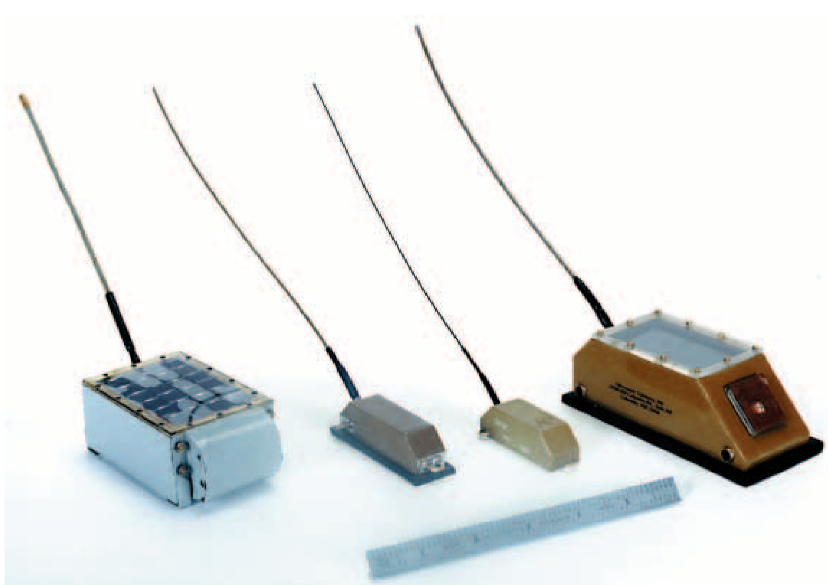

Figure 5. Argos platform transmitter terminals, left to right: Early solar-powered PPT (APL), 30- and 20-g Nano PPTs (Microwave Telemetry, Inc.), and prototye solar-powered GPS/PPT (Microwave Telemetry, Inc.).

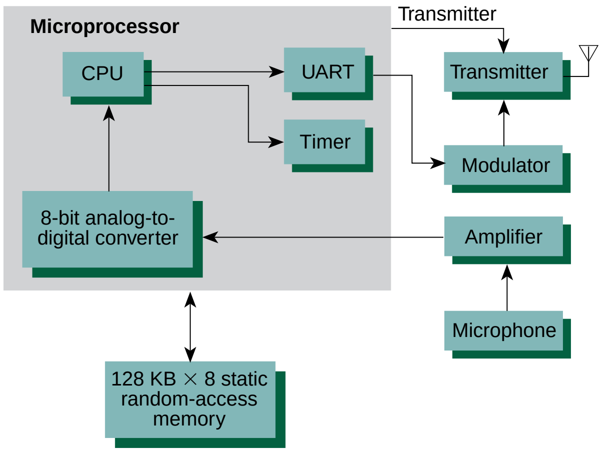

Figure 6. Block diagram of the audio capture and transmission system showing the central processing unit (CPU), universal asynchronous receiver transmitter (UART), and other system components.

the electret condenser microphone. The audio sample is then immediately stored in memory for future transmission.

The 8-bit microcontroller can directly address only 64 kilobytes (KB) of memory space. Therefore, page-mode addressing is implemented using a separate output bit to control the highest address line (A16) of the memory. If more than 128 KB of memory is required in future versions, enough spare gates and microprocessor output pins are present on the existing design to increase memory to 512 KB.

The initial memory configuration, which used two 32-KB memory chips, was replaced with a single 128-KB memory chip. The sampling rate, which can be easily changed in software, was set at 6000 samples per second to yield reasonable quality audio playback. Initial experiments were conducted with a sampling rate of 2700 samples per second and proved to yield marginal results for the intended system use. There is a direct trade-off between sampling rate and total record time. At 6000 samples per second and using 128 KB (actually 131,072 bytes) less 4096 bytes for EEPROM (and the image of EEPROM in upper memory, which is inaccessible in the present implementation), the total record time available is 126,976/6000 = 21.1 s.

The microprocessor's on-chip UART is used to generate the serial data stream during transmission. The data rate is programmable and has been set to 9600 bits per second because of requirements of the prototype modulator. The data rate is not infinitely flexible; it is obtained from selectable divide ratios of the microprocessor's clock. The present data format is 8 data bits per word with 1 start bit, 1 stop bit, and no parity bit. Lastly, during transmission, a line called transmit is brought low to activate the transmitter. This line activates the transmitter approximately 200 ms before data transmission starts to allow the transmitter to stabilize. This microcontroller portion of the system may also serve as the control for future features such as a GPS receiver. The microprocessor will then reformat and transmit the data either through the Argos satellite or to a ground-based receiver.

We anticipate that the entire digital portion of the audio capture system, including the microphone, could be built on a 5 × 5 cm circuit board weighing about 16 g. All components used in the design are available in surface-mount packages. The prototype breadboard and a mock-up of the circuit board for the actual bird-mounted unit are shown in Fig. 7. The breadboard includes components for audio playback testing not required in the actual device and not included in the mock-up.

Miniature Video Camera

The image sensor chosen for the miniature video camera application is a highly integrated complementary metal oxide semiconductor device. The single chip, VVL 1070 (made by VLSI Vision Limited, United Kingdom), is a functionally complete monochrome camera able to generate either analog or digital output. The sensor array has a pixel dimension of 160 × 160. Each square pixel is 10.5 μm on a side. When the camera is configured to generate an analog signal, each frame is preceded by a synchronization pulse. When configured for digital output, the camera generates an 8-bit serial or parallel data stream. Each pixel's intensity is 8-bit quantized, giving an intensity dynamic range of 256 to 1.

The camera packaged chip measures 1.7 × 1.7 cm, is 0.267 cm high, and weighs less than 2 g. The camera requires a modest amount of external circuitry for analog signal generation. At present, the camera is mounted on a circular circuit board with a diameter of 3.18 cm (Fig. 8). The camera requires a regulated 5-V, 20-mA power supply.

The camera's exposure can be set to either automatic or manual mode. In manual mode, the exposure is set by incrementing (or decrementing) the contents of the exposure register. In automatic mode, the camera dynamically varies the exposure so that the average pixel's intensity lies halfway at its maximum. The facility to electronically control the exposure allows the use of a simple, inexpensive, fixed-aperture lens. The camera's frame rate (i.e., exposure time) is variable between 0.5 and 24 frames per second. If it is desirable to view dynamic scenes (scenes that may change over a period of 40 ms), an external shutter will have to be incorporated into the camera's operation.

For an application such as animal monitoring, where the camera will be operated remotely from its central

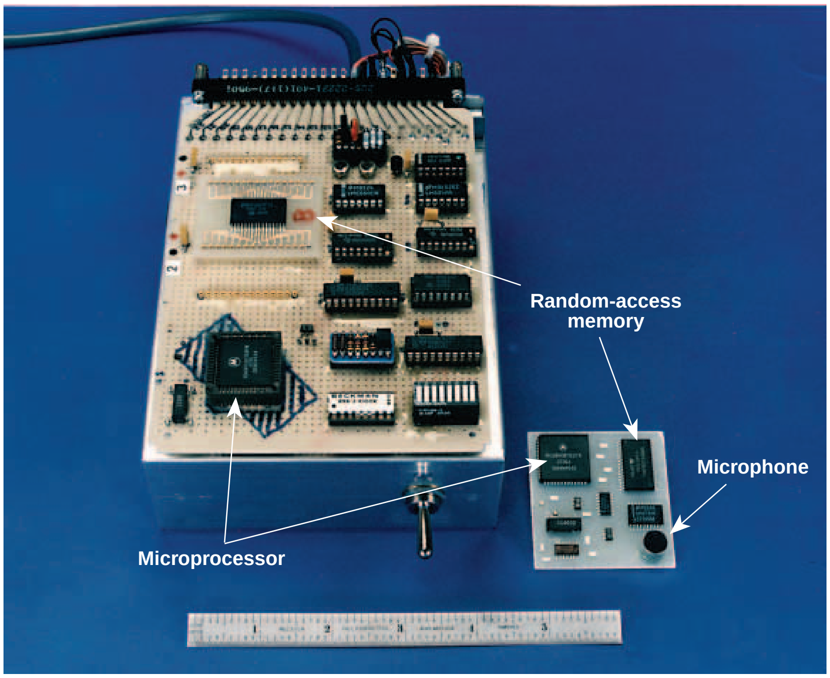

Figure 7. Photograph of the breadboard (left) and mock-up (right) of the digital audio capture system.

control, the digital mode is preferable because the image data can be stored indefinitely aboard the sensor package and transmitted at a pre-arranged time. Using the camera in analog mode would require real-time broadcast of the video signal, complicating the sensor power management (because the radio frequency transmitter is the biggest consumer of electrical power).

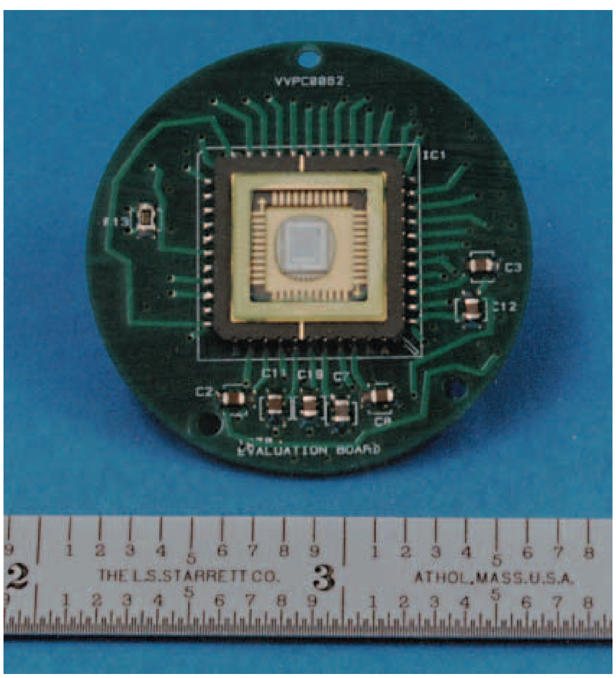

Figure 8. Miniature single-chip camera. (Note: The scale shown is in inches.)

A GPS-Qualified Argos PTT

The Argos system can provide locations to within ±150 m anywhere on the surface of the Earth, but locations obtained from tiny, low-power (100 mW) Argos beacons, mounted on the backs of birds, often give locations in the range of ±2 km of the birds' true locations. To achieve the highest-grade Argos location, at least four messages must reach the satellite over a period exceeding 420 s. A single Argos message can relay up to 256 bits of information from sensors on the transmitter to the user via the satellite.

The availability of small commercial GPS receiver modules has now made it possible to combine such a receiver with an Argos transmitter and field a package small enough to be carried by an eagle-size bird. By scheduling the collection of GPS locations throughout the day and storing these positions for later transmission via Argos, as many as 20 GPS positions (±20 m) can be transmitted to the user in a single Argos message.

The present Argos/GPS package under development by Microwave Telemetry, Inc., incorporates a commercially available GPS receiver, a microcontroller-based data logger, and a Microwave Telemetry PTT. The data logger controls the GPS receiver and the collection of GPS data, which is dependent on the availability of power from the solar-charged power source. The data logger then sequences data transfer to the PTT at times favorable to satellite availability. The prototype unit is now undergoing laboratory testing; it weighs less than 200 g.

The satellite transmitter, audio capture, and video circuitry could be further miniaturized by taking advantage of chip-on-board packaging, stacked-die techniques, and application-specific integrated circuit development. Development of these high-level circuit integration techniques is currently being pursued at a variety of companies and research laboratories, including APL.

DISCUSSION

The technology we have described is designed for use on free-ranging animals to provide data on their locations, behavior, and environment. A GPS receiver integrated with an Argos PTT will provide more accurate location data that can be collected at predesignated times. The Argos system is dependent upon collecting frequency data on the PTT signal transmission to calculate a single time-dependent location. With the use of a minicomputer integrated into the unit, GPS positions can be collected according to a programmed schedule to increase our ability to locate free-ranging animals and to derive important facts regarding range and habitat use. With enhanced accuracy and greater numbers of locations, home range estimations, programs, and subroutines in geographic information systems can be used more effectively to relate animal movements to jurisdiction boundaries, habitats, and land-use activity maps.

Sensor data, combined with time and location, can provide additional information relevant to natural resources. For example, the behavioral noise monitor is designed to recognize animal vocalizations, thus allowing evaluation of animal behaviors and specific activities. By locating exact animal behaviors and linking them to specific habitats within the animal's range, valuable information can be collected on relationships among animals and microhabitat components of their range. Time-coded information on location, heading, altitude, speed, ambient temperature, humidity, and other sensor data can be displayed and analyzed relative to other geographically linked features such as geomorphology, ecological community, meteorology, and land-use activities. Free-ranging animals tagged with animal track and monitor units act as sentinels in the population. These sentinels, moving either alone or in herds or flocks, can reflect the activities of many animals and enhance the biological database dramatically.

Biologists and military operations staff can integrate a real-time military training monitor system, such as the Deployable Force-on-Force Instrumented Range System (DFIRST), with natural resource information. The DFIRST system allows commanders to track military training activities and monitor units (armored vehicles, etc.) simultaneously in real time. This system can provide locations of equipment and troop movements on an installation. This database, when layered into a geographic information system with natural resource data, can be used to evaluate the effects of military land-use activities on natural resources. In such a system, models could be developed for each installation that would monitor vegetation, habitat, key sentinel animals, and military activities, and in near real time examine the cause-and-effect relationships that exist among these elements. This system approach will enable environmental planners and military managers to develop a natural resource forecast function that brings a dynamic prediction and planning component into the process of installation management.

The military is beginning to integrate natural resource issues and mission planning to foster ecosystem management, protect biodiversity, and enhance conservation where such measures can be linked to readiness. Such an approach also will allow for maximum flexibility to achieve readiness. The technology-based systems being developed here will allow the early integration of military mission planning activities with natural resource information, thus dynamically supporting both environmental and military requirements.

The process of resource management on military installations begins with a thorough inventory and description of the natural system and the land-use activities. Programs such as the DoD Legacy efforts are directed at demonstrating data acquisition for installations and maintaining the information for local, regional, and national planning and management. An inventory provides information on the presence and range of flora and fauna on a local to regional scale and delimits habitat and ecosystem parameters. With the development and use of remote tracking and monitoring technology, we will be able to provide methods, hardware, and systems that will allow planners and managers to meet both military and environmental requirements quickly, with good information, and with minimal interruption to regular base activities.

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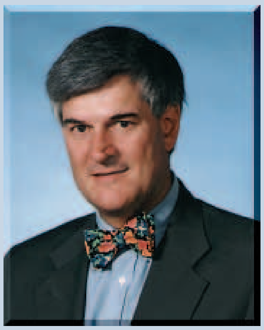

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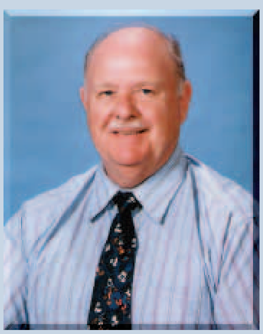

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