AUTOMATED ANIMAL-TRACKING SYSTEM:
Tracking Elk with Retransmitted Loran-C

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ABSTRACT

An Automated Animal-Tracking System (AATS) has been deployed at the Starkey Experimental Forest near La Grande, Oregon. AATS provides position data on elk, deer, and cattle using paged animal collars retransmitting 12-second bursts of Loran-C signals. Processing includes cross rate blanking, RF averaging, differential cycle tagging, phase measurements, noise estimates, and computation of differentially corrected time differences. Positioning software provides Easting and Northing coordinates for an animal collar position within the 40-square-mile study area every 15 seconds. Redundant data storage and digital map displays complete the system.

INTRODUCTION

The Starkey Project consists of long-term studies of elk, deer, and cattle in managed forests at the United States Department of Agriculture Forest Service Starkey Experimental Forest and Range near La Grande in northeast Oregon. The 25,000-acre study area is enclosed by 27 miles of specially designed elk- and deer-proof fence. An intensive forest management area and a winter feed and handling area are enclosed within Starkey by an additional 11 miles of "elk fence" [Figure 1].

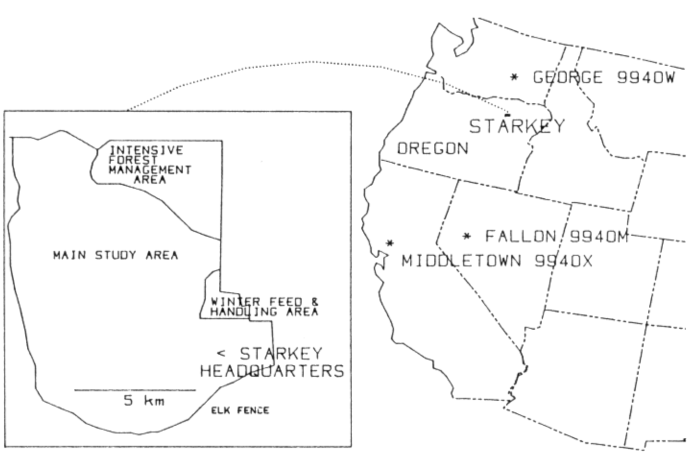

Figure 1. The Starkey Project

Four major studies are being conducted at Starkey by USDA and Oregon Department of Fish and Game researchers. Three studies measure the effects on wildlife of intensive forest management, roads and traffic, and cross-grazing of animals. The fourth investigates the relationship between bull elk age and breeding. A system to provide position information on 60 elk, 60 deer, and 60 cattle is required to implement these studies.

Using retransmitted Loran-C, the Automated Animal-Tracking System (AATS) continuously provides position and air temperature data from collared animals anywhere within the enclosed study area. The data are displayed in real time and stored for later analysis by mainframe computers where they are combined with as many as 80 habitat features and other data such as heart rate and respiration from monitors installed on selected animals.

AATS DESIGN

AATS was designed and built by the Navigation and Weather Division of Tracor Aerospace, Inc., in Austin, Texas. Although the system can be deployed anywhere with Loran-C coverage, AATS was designed to meet the specific requirements of the Starkey Project.

Positioning System Requirements

The system must track 180 collared animals within the enclosed 25,000-acre area of the Starkey Project continuously and automatically without operator intervention. The position of each of the collars must be available at least once an hour with an accuracy of better than 200 meters (one standard deviation). Air temperature at the animal collar position is required, as well as the potential for adding other sensors. Temperature data are used to relate animal energy expenditures to changes in habitat from timber management.

Position, temperature, and signal quality information must be time tagged and saved on mass storage devices. Animal collars are required to weigh less than 3 pounds; because of the difficulties in installing collars on animals, particularly on elk and deer, collar batteries must last at least eight months. The animal collars must allow for battery changing and must be both environmentally sealed and able to withstand the shock and vibration expected on large animals.

Positioning System Selection

The requirements of the Starkey Project dictated the selection of an appropriate positioning system.

Available Systems

Conventional animal telemetry collars and sensors are available from several manufacturers. With these systems, researchers take bearings and/or signal strength readings to locate a collar. Bearing accuracy is limited, requiring researchers to move closer and closer to the target animal to improve position accuracy. Multipath can increase bearing errors further degrading system performance. Conventional telemetry may require more than one researcher and many hours to locate a single animal. If position coordinates are required after the animal is located, the researcher must provide them.

Many dedicated area systems are available; several, including Loran-C minichains and 2-MHz systems, could provide positioning at Starkey. All require large investments in transmitters and control systems. The need for long battery life because of the difficulty of trapping animals made many conventional receivers inappropriate.

Satellite systems are not yet available that could meet the multiple positioning and long battery life requirements at Starkey.

After a feasibility study in the spring of 1988, retransmitted differential Loran-C using paged collars was selected as the positioning system.

Loran-C Coverage

The three Loran-C transmitters that now provide positioning for the Starkey site are George, WA, Fallon, NV, and Middletown, CA, on the 9940 group repetition interval (GRI).

The ranges, predicted signal-to-noise ratios (SNR), and field strengths are given in Table 1. The geometric dilution of precision (GDOP) in meters per microsecond for the site is computed from the gradients of the two time difference (TD) lines of position (LOP) [Table 1]. The GDOP is 814.27, with a Northing component of 218.6 and an Easting component of 784.4. When the Mid-Continent chains are operational in 1991, the GDOP will be reduced to around 420 meters per microsecond with a reduced Easting component.

TRANSMITTER	RANGE (km)	SNR (db)	FIELD STRENGTH (db/uv/m)
George	215	+35	+86
Fallon	640	+12	+63
Middletown	790	+ 8	+59

TIME DIFFERENCE LINE OF POSITION	GRADIENT (m/us)
Fallon-George	153.1
Fallon-Middletown	729.7

Table 1. AATS Loran-C Groundwave Parameters

Skywave arrival time and amplitude computations for the area use prediction methods from Reference 1. The delays with respect to the groundwave given in Table 2 are possible for first-hop skywaves for normal day and night ionospheric heights for ranges +/- 20 km from the center of the Starkey site. The earliest "normal" skywave is at 54 microseconds.

Skywave to groundwave amplitude differential predictions for earth-path conductivity groundwaves are listed in Table 2. The largest "normal" skywave amplitude is +5db above the groundwave amplitude. Envelope correlation between 20 to 40 microseconds is unaffected by skywaves anywhere within the Starkey area.

Skywave Delays +/-20km from AATS Center for Nominal Day and Night Ionospheric Heights

IONOSPHERIC HEIGHT:	DAY (70KM)			NIGHT (90KM)		
RANGES FROM CENTER:	-20KM	0	+20KM	-20KM	0	+20KM
TRANSMITTER	GROUNDWAVE-SKYWAVE DELAY (us)					
George	153	142	132	238	222	208
Fallon	63	62	61	99	97	95
Middletown	56	55	54	86	85	84

Skywave to Groundwave Amplitude Ratios (db)

TRANSMITTER	FIRST HOP DAY	FIRST HOP NIGHT
George	-40	-30
Fallon	-15	0
Middletown	- 5	+ 5

Table 2. AATS Loran-C Skywave Parameters

The predicted envelope to cycle differences (ECD) in microseconds for each transmitter are: George, 2.7; Fallon, 2.6; and Middletown, 1.9. A nominal 2.5-microsecond ECD offset for all three stations allows cycle selection aiding in the envelope correlation software.

The George transmitter transmits at both the 9940 and 5990 rates. The crossing rate between these GRIs is at 59.5406 seconds with a phase interference rate of 119.0812 seconds. Field tests at Starkey indicated that blanking on the George 5990 rate was necessary to avoid cycle tagging problems based on 10-second averages.

An on-site survey of Loran-C signals was conducted in May 1988. The Starkey site is made up of rolling hills covered with pine forests and pastures with elevations ranging from 3200 to 4800 feet. The site was found to be suitable for Loran-C signal reception because the measured signals were within predicted bounds in all but the steepest canyon areas.

AATS Concept

The result of the initial design phase was a system based on paged animal collars and differentially corrected retransmitted Loran-C [Figure 2]. A control and signal processor computer (CSPC) initiates the paging of each collar, the collar electronics are switched on, and Loran-C signals are received and retransmitted on a 216.5-MHz VHF radio signal [Figure 3]. The VHF signal is received and demodulated, and the Loran-C signals are sent over a microwave link [Figure 4] to filtering hardware. The filtered signals are sampled at a 2.5-microsecond rate during 320 millisecond windows triggered by a continuously tracking monitor. The sample windows are centered on the monitor arrival times and span the limits of the possible arrival times of remote signals from anywhere within the limits of the Starkey area. The samples are phase coded and summed over a 100-GRI period by a custom PC/Loran-C interface card (PCLC) and transferred under interrupts to the CSPC. The CSPC processes the Loran-C signals, computes time differences, corrects them differentially and computes collar positions. These positions are time tagged and stored, then displayed and transferred to the data display and storage computer (DDSC) that provides redundant storage and an interactive map display.

Simulation and Concept Testing

Loran-C processing techniques were investigated, and a computer simulation was developed to test methods for envelope and phase correlation. A prototype system was implemented and run in Austin, TX, tracking the 7980 chain. The results of simulations were compared to real tracking data.

In June 1988, a proof of concept test was conducted at the Starkey site. A "PC AT" type of computer, a 400-MHz wind finding receiver, a II Morrow Loran-C receiver, and a wind finding radiosonde retransmitter tested the feasibility of retransmitted Loran-C. The test consisted of tracking a prototype collar carried over much of the Starkey range on an automobile, on a four-wheel all-terrain vehicle, on foot, and on horseback. The II Morrow receiver antenna input was switched from the normal antenna to the retransmitted signal under computer control. Individual position reports were recorded, differentially corrected by position offsets, converted to NAD 1927 UTM coordinates and plotted on a computer map in real time. Since no accurate geodetic reference was available, the position bias was assumed to be zero. The position noise was between 34 and 74 meters (one standard deviation) for static positioning tests.

In February 1989, Forest Service personnel tested a Motorola paging system at Starkey. Pager "beepers" were carried on snowshoes, cross-country skis, and snowmobiles over most of the site. A single 50-foot temporary tower provided paging to all but a few canyon areas of the Starkey range.

A prototype version of the system was tested at Starkey in March 1989. Most of the features of the system were tested with

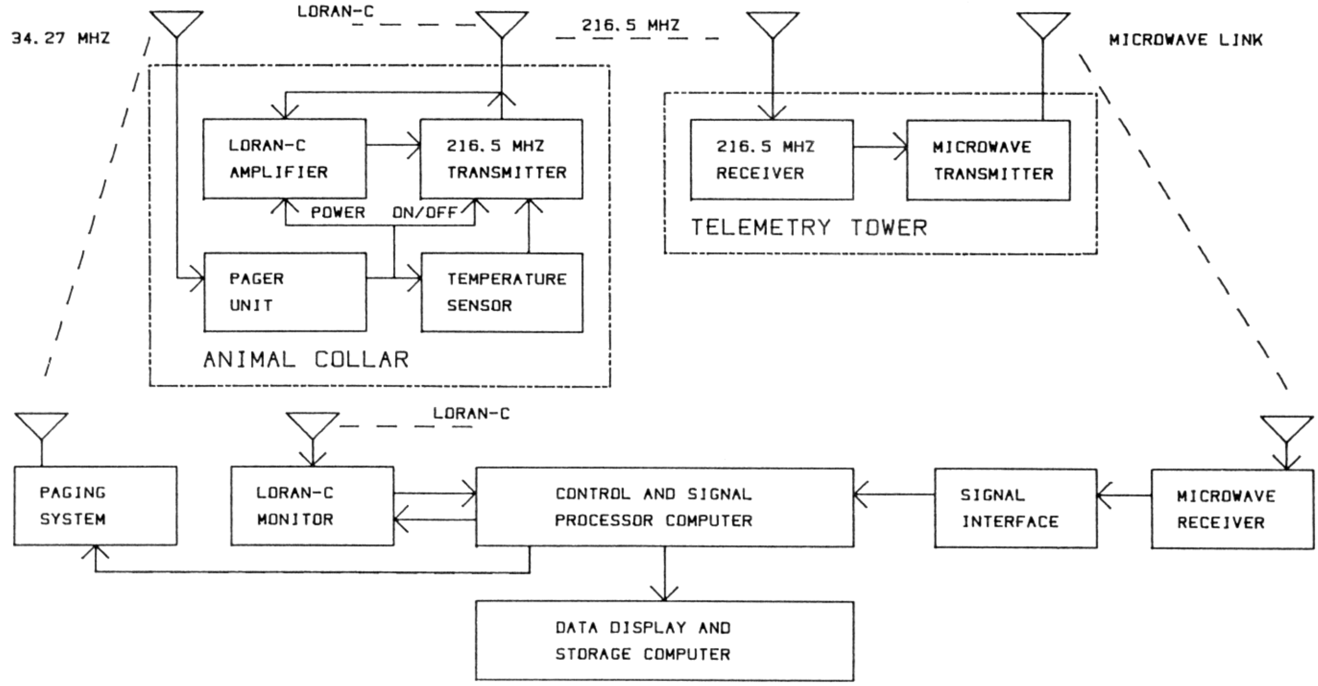

Figure 2. Automated Animal-Tracking System

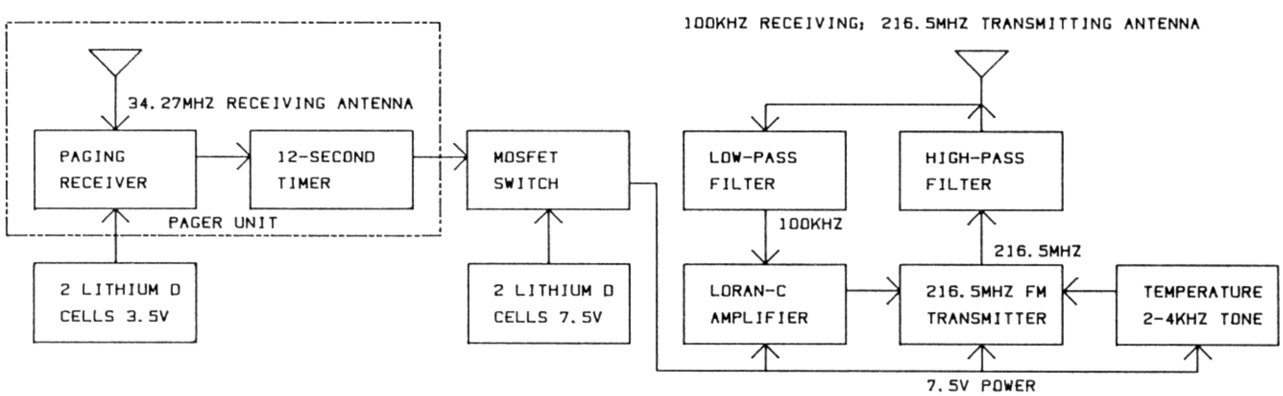

Figure 3. AATS Animal Collar Electronics

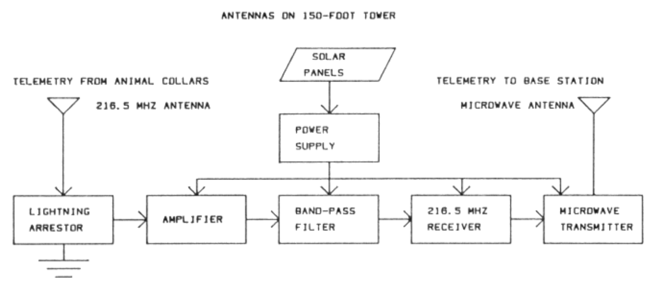

Figure 4. AATS Telemetry Tower

two collar units, the CSPC, an Internav LC408 monitor receiver, and the paging system. Modifications resulting from the test included cross-rate blanking and large-signal attenuation.

AATS IMPLEMENTATION

AATS was contracted for in September 1988 and was to be deployed in June 1989. This nine-month schedule required the use of existing designs and commercially available equipment wherever possible.

Loran-C Monitor Receiver

An Internav LC408 dual-chain Loran-C monitor receiver is the differential system area monitor and the source of hardware strobes to trigger sample taking in the PCLC and to control cross-rate blanking and large-signal attenuation in the signal interface hardware.

The LC408 is controlled over a two-way 9600-baud RS232 link. TDs and status are transmitted on request from the control computer. The monitor is reset over the link if the TDs on the primary chain differ from the predictions for the monitor antenna site by more than 7.5 microseconds. The LC408 has two strobe outputs for each of the two chains it tracks. Sample strobes occur eight times each GRI for each station tracked, and master strobes occur once each GRI. These are used to trigger the sampling of 128-word Loran-C samples in the PCLC.

The PCLC uses the master strobes for the primary chain to synchronize the sampling triggers with the start of the GRI and to maintain phase code counting between requests for 10-second averages. Master strobes trigger the large-signal attenuator for the primary chain and the cross-rate blanker for the secondary chain.

Paging System

A Motorola People Finder paging system polls individual collars. This sub-system consists of a control consol, a 32-MHz transmitter, an antenna, and individual pager units. An RS232 link from the CSPC sequentially pages each collar pager number, the link is tested to ensure that the People Finder is responding, and a timer is started in the software. After 1 second the People Finder transmits. After 2 seconds the paged unit responds by switching on the collar electronics. Signal gathering is done during the middle 10 seconds of the 12-second pager-on cycle. The system reaches pagers over most of the Starkey area with the antenna at the top of a permanent 150-foot tower.

Retransmission System Components

The retransmission system consists of remote and local collars, VHF receiver, microwave link, system clock, and interface hardware.

Animal Collars

The animal collars are completed and installed at the Starkey site by Forest Service personnel. The electronics package is manufactured by the contractor and consists of batteries, Loran-C receiver, VHF transmitter, and a pager connected to a 2-inch strip of rubberized material containing a ground strap and a mounting fixture for the antenna.

The batteries for the collar electronics are lithium cells with a 14-amp-hour continuous load rating. When turned on, the collar electronics draw 100 milliamps allowing 140 hours of continuous operation. Since the electronics are polled and remain on for 12 seconds, the batteries can power 42,000 cycles. The nominal polling cycle for 180 animal collars at 15 seconds each is once each 45 minutes. At that rate a collar can last 1300 days. With a faster update rate of one query every 6 minutes, a collar could remain powered for 8 months. The batteries for the pager are 28-amp-hour lithium cells that can provide continuous operation of the 1.8-milliamp pager for 648 days.

The Motorola pager is modified by removing the light and beeper normally activated by paging, and replacing them with a power-on switch for the collar electronics. The pager is then dipped in a rubberized sealant for attachment to the collar.

A Loran-C amplifier is connected to the collar antenna through a low-pass filter. A 216.5-MHz FM transmitter, modulated by both Loran-C and the 3 kHz temperature sensor tone, is connected to the collar antenna through a high-pass filter.

The collar antenna is both a Loran-C receiving and a 216.5-MHz transmitting antenna. It is a 13-inch quarter-wavelength antenna fabricated from a strong, flexible material and has been field tested on cows and elk for many months without damage beyond a slight bending.

The electronics are placed within a PVC pipe that is heated and placed into one of several molds, depending on the animal type. The heated pipe cools into the final collar shape and is painted with numbers and color codes before being fastened around the neck of the animal.

VHF Receiver

A 216.5-MHz antenna is mounted at the top of a 150-foot remote tower. This antenna is connected through a lightning arrestor to the VHF telemetry receiver at the tower base. This receiver, adapted from a design used for many years by the contractor for wind finding retransmission signals, transfers the Loran-C and temperature signals to the microwave link.

Microwave Link

A Motorola Starpoint microwave link transfers Loran-C and temperature signals from the remote VHF receiver to the 150-foot tower at the control site. The link is run without the normally installed multiplex unit allowing the full bandwidth of the link for Loran-C signals.

System Clock

The system clock is a 10-MHz Efratom rubidium oscillator. The clock is used by the temperature tone decoder, the LC408 monitor receiver, and the PCLC. The frequency stability of the oscillator allows Loran-C samples to be phase coherent during the 10-second averaging.

Local Reference Collar

A collar identical to the animal collars is mounted next to the LC408 antenna. This local collar provides a reference signal used for cycle selection, for timing of the sample windows triggered on the PCLC, and for system self-test through periodic reference collar paging.

Signal Interface Hardware

In the signal interface hardware, an amplifier and a bandwidth-limiting filter condition the Loran-C signals.

The master pulse from the primary LC408 chain triggers an adjustable timer that provides an attenuation window for the

George signal, reducing it by 24 db to lessen the gain variations seen by the PCLC. The master pulse from the secondary chain triggers an adjustable timer that provides a blanking window on the large 5990 George signal. In other locations these timers can be adjusted to attenuate any one large signal and blank any one cross-rate signal.

The air temperature tone is converted in the interface hardware to a binary count. The eight bits are updated once per second, are latched into a parallel port, and are transferred to the CSPC on request.

Control and Signal Processor Computer

The entire system is controlled from the CSPC, a Dell System 200 12-MHz 80286 PC with 3.5- and 5.25-inch drives, 40-Mbyte hard disk, and tape backup system. With the exception of the interrupt code for the PCLC, all the software in this computer is written in "C". The computer has three RS232 links: one controls the People Finder, another controls the LC408, and the third transfers data to the DDSC. A parallel port allows transfer of temperature data from the signal interface hardware.

Initialization and Control

The CSPC reads five ASCII test files on power up that control the operation of the system. Changing these files allows the system to run with new lists of animals, new tracking schedules, or at other locations. The SYSREF.DAT file contains system parameters including monitor antenna location in Loran-C system coordinates (latitude and longitude), monitor UTM Easting and Northing, fixed map scale and center, and Loran-C station identifiers. The LORANC.DAT file contains the Loran-C system coordinates for all of the Loran-C stations by identifier used by the SYSREF.DAT file. The ELKPAGER.DAT file contains the list of pagers to be polled. The SCHEDULE.DAT file contains start and stop times and file names of pager numbers to be scheduled each day. If no file name is present or no file name is scheduled for a particular time, the default file ELKPAGER.DAT is used. The PAGECOLOR.DAT file equates pager numbers with color numbers to represent elk, deer, and cattle on map displays.

PC/Loran-C Interface Card

The PCLC was designed for the AATS application and fits in a slot in the CSPC. The card digitizes 12 bits of Loran-C RF signal at 2.5-microsecond intervals derived from the 10-MHz rubidium clock. Two parallel 128x8-bit FIFO (first in first out) buffers transfer the samples to the CSPC.

To initiate a sampling cycle, the CSPC software clears the FIFO buffers, resets an interrupt request flip-flop, and arms a circuit that detects the LC408 sample strobe (ST).

As RF samples are taken they are pushed into the FIFOs. The oldest samples are discarded to make room for the newest ones so that 127 RF samples are retained. At the ST signal, a counter is enabled to accept 64 more RF samples into the FIFO buffer and then cease sampling. An interrupt request is then generated to signal the software that a digitized RF pulse is available in the FIFO buffer. A flip-flop monitors the LC408 master trigger, returning this event timing to the software for maintaining sample alignment and phase code count.

Since Loran-C pulses are at millisecond intervals, the software has less than a millisecond to process the digitized pulse and initiate the next sampling cycle. To achieve the necessary speed, the interrupt service routine is written in 80286 assembly language.

The application software uses subroutine calls to set up averaging buffers for the master pulses and for each set of secondary pulses. Other calls initiate and terminate averaging into the buffers. A subroutine is called to switch phase coding from ABA to BAB coding whenever the local reference collar signal strength is below a threshold value. The interrupt service routine counts each master strobe to maintain phase code synchronization once achieved. When averaging is active, RF samples are accumulated into appropriate averaging buffers with positive or negative sign as required by the phase code. The CSPC "C" program polls the status of the averaging process. When averaging is complete, the current buffers are released for use by the signal-processing software.

Loran-C Signal-Processing Software

Gathering of RF sample windows is initiated by a call to the PCLC software to begin sampling for 100 GRIs (9.94 seconds). While sampling is in process, the previously gathered samples are processed to form time differences and position data.

Signal processing starts by forming averages from the summed signals. Any DC offset is removed from the 10-second average at this time. An RF envelope is made by taking the square root of successive sums of squared samples [Figure 5 F]. This envelope is then smoothed by an exponentially weighted eleven-point running average [Figure 5 G]. This low-pass smoothing reduces the effects of noise and cross-rate interference on the envelope shape.

The smoothed envelope is processed to find the first peak. The sample index of the maximum envelope value is used as the first candidate index. The search moves toward the front of the pulse, rejecting sample indices any time samples increase in value, until a peak is found that is preceded by only decreasing samples. This process continues until an envelope value 12 db less than the current peak candidate value is reached.

The smoothed envelope is tagged at the "sample point" by searching for the sample index that is the best fit to the "phase" of a theoretical Loran-C envelope passed through the same smoothing. Envelope phase is measured by ratios of envelope samples at 10 microsecond intervals. A best fit is found by minimizing the sum of the squared differences between measured and predicted values [Figure 6].

The averaged RF samples are normalized by the smoothed envelope values around the time-tagged index [Figure 5 H]. Phase is measured by taking the four-quadrant arc-tangent of two consecutive differences of alternate normalized RF samples.

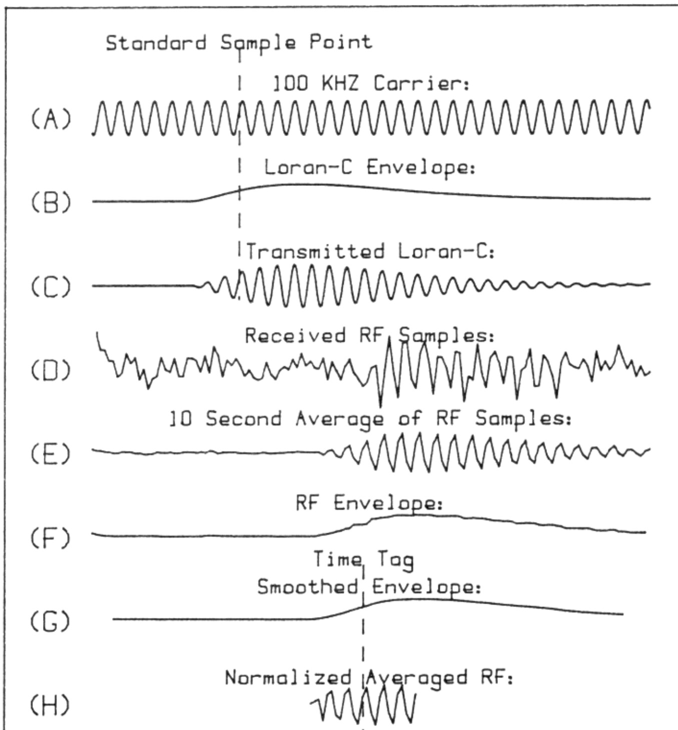

Figure 5. AATS Loran-C Processing

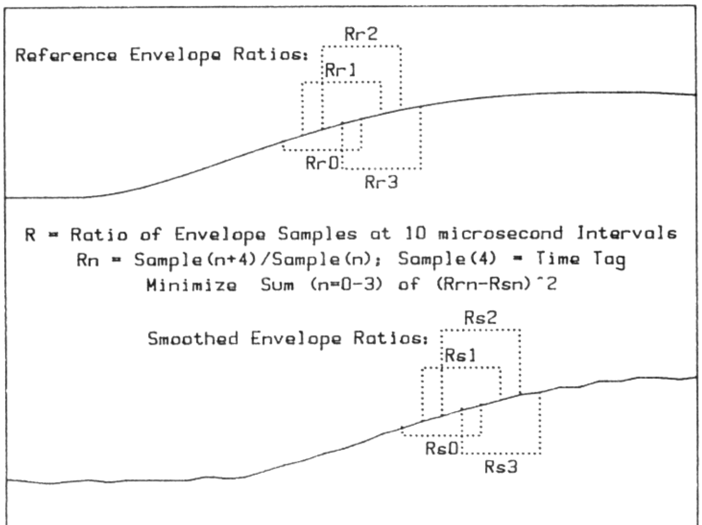

Figure 6. AATS Loran-C Envelope Correlation

Phase differences from the local reference collar are measured and compared to the phase differences measured by the system area monitor (LC408). Corrections are computed that count the number of 2.5-microsecond sampling intervals between windows. These counts correct both for ECD differences between master and secondary and for the exact positioning of LC408 strobes and the sampling triggers derived from the rubidium clock. The 2.5-microsecond local reference collar corrections are applied to the measured index count differences. These 2.5-microsecond count differences are added to the phase differences to produce TDs for tracked secondaries.

Differential corrections are produced by comparing LC408 TDs to TDs predicted for the LC408 antenna location on startup. The differentially corrected TDs are passed to the positioning software.

Positioning Software

A complete processing cycle for AATS takes place every 15 seconds. Positioning software was optimized for speed with a two-step process that avoids time-consuming recomputation of geodetic ranges and bearings for position solutions.

Remote TDs are differenced with TDs predicted at an estimated position. The estimated position is then moved by multiplying the TD differences by a covariance matrix computed from a matrix of directional derivatives.

In the AATS process, accurate range and azimuth computations are made once, on power-up, from the system area monitor antenna reference position to each of the Loran-C transmitters. Each transmitter is remapped to a local tangent plane system with the reference position as the center. The accurate geodetic ranges and azimuths convert to transmitter positions in X and Y offsets from the reference origin. Directional derivatives for the initial covariance matrix are precomputed from reference azimuths and their sines and cosines.

Earth-path predictions in microseconds are made using a curve fit derived from Reference 2 for 5 millimhos per meter conductivity for ranges in meters at distances over 160 kilometers: path = range/299.691162387 + 6463.270345/range + .649893 + 4.44343E-6Xrange.

For each set of remote collar time differences, the AATS positioning method outline is:

- Set estimated position to the system monitor location.
- Set reference origin to 0,0.
- Set transmitter azimuth sines and cosines to reference values.
- Set TD predictions to precomputed values.
- Fill covariance matrix and inverse from reference azimuth sines and cosines.
- Compute predicted TDs minus observed TDs.
- Solve for the X and Y correction.
- Move the estimated position by the X and Y correction.
- Reset the reference origin to the X and Y correction values.
- Compute new ranges to the transmitters from estimated position XY and transmitter XYs.
- Compute new azimuth sines and cosines from transmitter XY values, new origin, and ranges from the new origin.
- Predict new land-path TDs.
- Compute new directional derivatives and covariance matrix from the new reference azimuth sines and cosines.
- Compute predicted TDs minus observed TDs.
- Solve for X and Y corrections.
- Move the estimated position by the X and Y corrections.
- Return estimated position in UTM Northing and Easting.

Three-station positioning is all that is required for the system used at Starkey now. The software can also do four-station positioning in areas where a fourth transmitter is available. This results in an overdetermined solution and can overcome noise and geometry problems at some locations. The software will use the appropriate methods for three- or four-station positioning automatically as determined by the transmitters defined in the SYSREF.DAT file.

Displays

The CSPC displays in real time the Loran-C signals, signal parameters, position parameters, and a map position for each remote collar as information is processed [Figure 7].

The bottom left of the CSPC screen is a map display of the Starkey area. Both vector and raster map sources are used. The elk fence boundary, roads, contours, and foliage coverage are mapped. Vector maps for the area contain road and fence data provided by the U.S. Forest Service. Other line and text maps can be produced in the required format using a MAKEMAP software package written for this project. A raster map file contains three forage-coverage densities from Landsat imagery: forage, marginal, and satisfactory. The coverage type is mapped by one of three colors and pixel dithering densities. Brown and a medium pixel density are used for medium cover. Green and a high pixel density are used for satisfactory cover. White and no dithering are used for forage (open field) habitats.

The top 80 pixels of the screen display the Loran-C data gathered during the previous interval. The RF samples, the smoothed envelope, and the sampling point are plotted. Under each sample window the phase, sampling point index, amplitude, and SNR are printed.

The right side of the screen is a text display, presenting software status and position and temperature data from each remote collar in turn.

The system stores on disk and outputs over an RS232 link a line of information for each paged unit. A new file name is used each day, composed from the system date and time, automatically sorting tracking data into 24-hour segments. The format for both disk storage and RS232 output is a single line with date, time, pager #, status, TDA, TDB, TDC, Easting, Northing, and temperature. The same line is sent over an RS232 port to the DDSC.

Data Display and Storage Computer

A second Dell System 200 80286 computer receives position reports from the CSPC [Figure 8]. All software for this computer is written in Turbo-C.

The top line of the screen displays the latest RS232 position report line. These are handled by an interrupt routine ensuring that they are not lost during operator interaction with the map display. These reports are stored on the hard disk of the DDSC in the same format as in the CSPC.

Data stored on the hard disk can be transferred to the 40-Mbyte tape backup system by running "Quick Stream" soft-

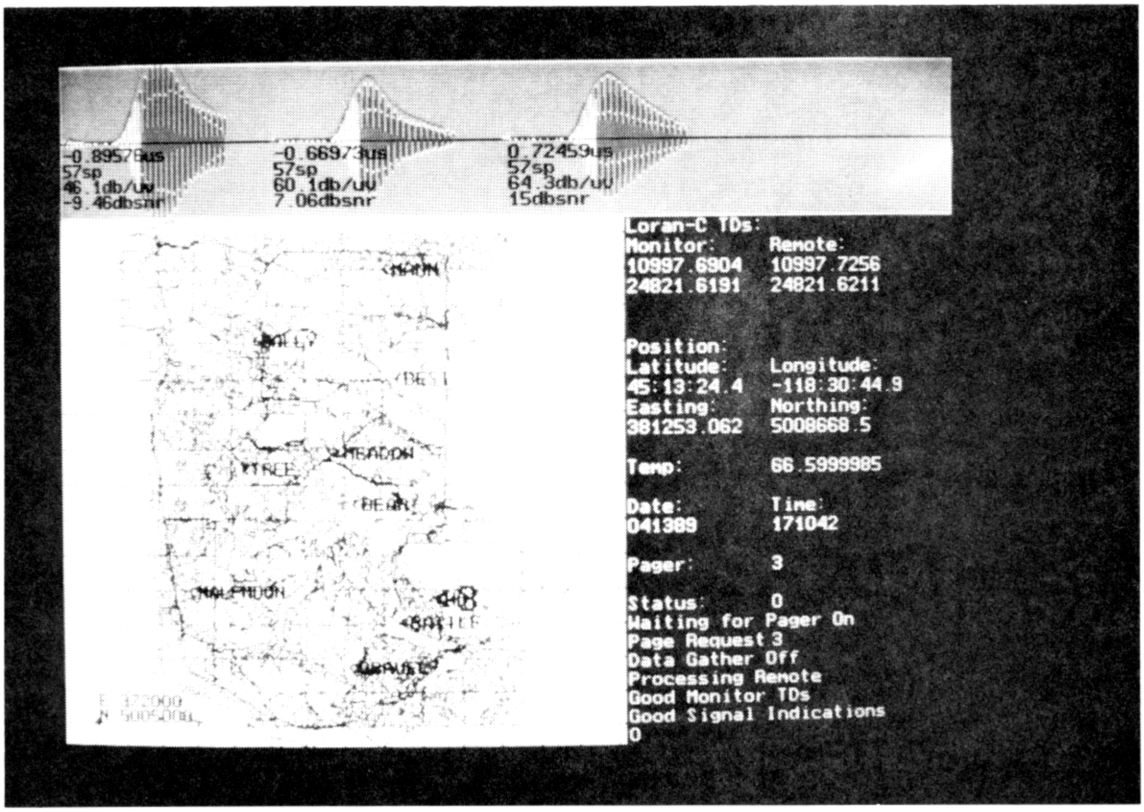

Figure 7. AATS Control and Signal Processing Computer Display

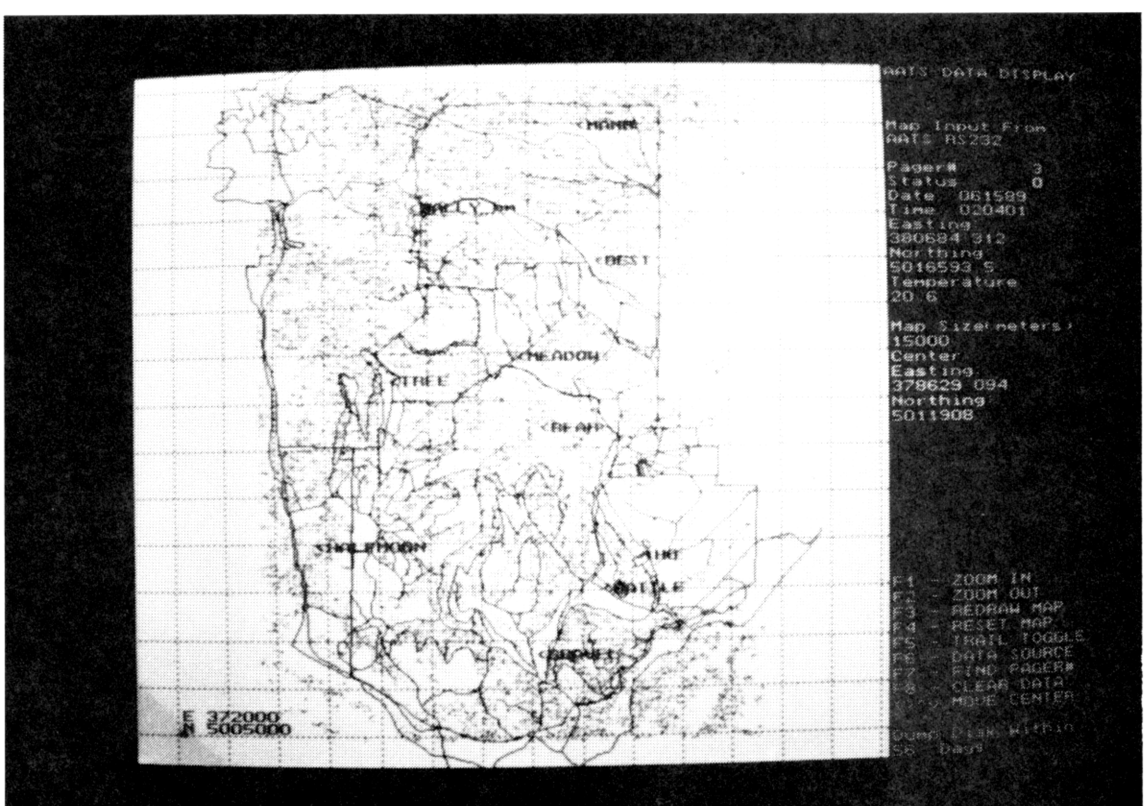

Figure 8. AATS Data Display and Storage Computer Display

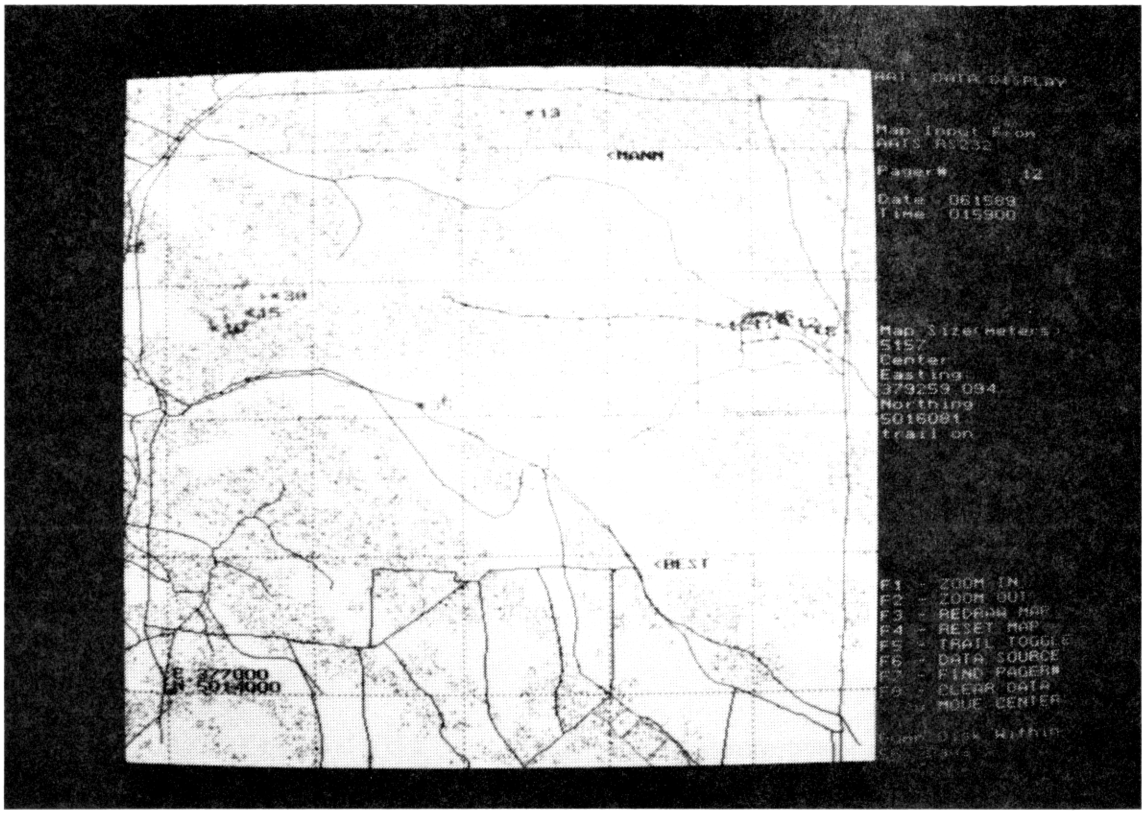

Figure 9. AATS Map Display of Intensive Forest Management Area

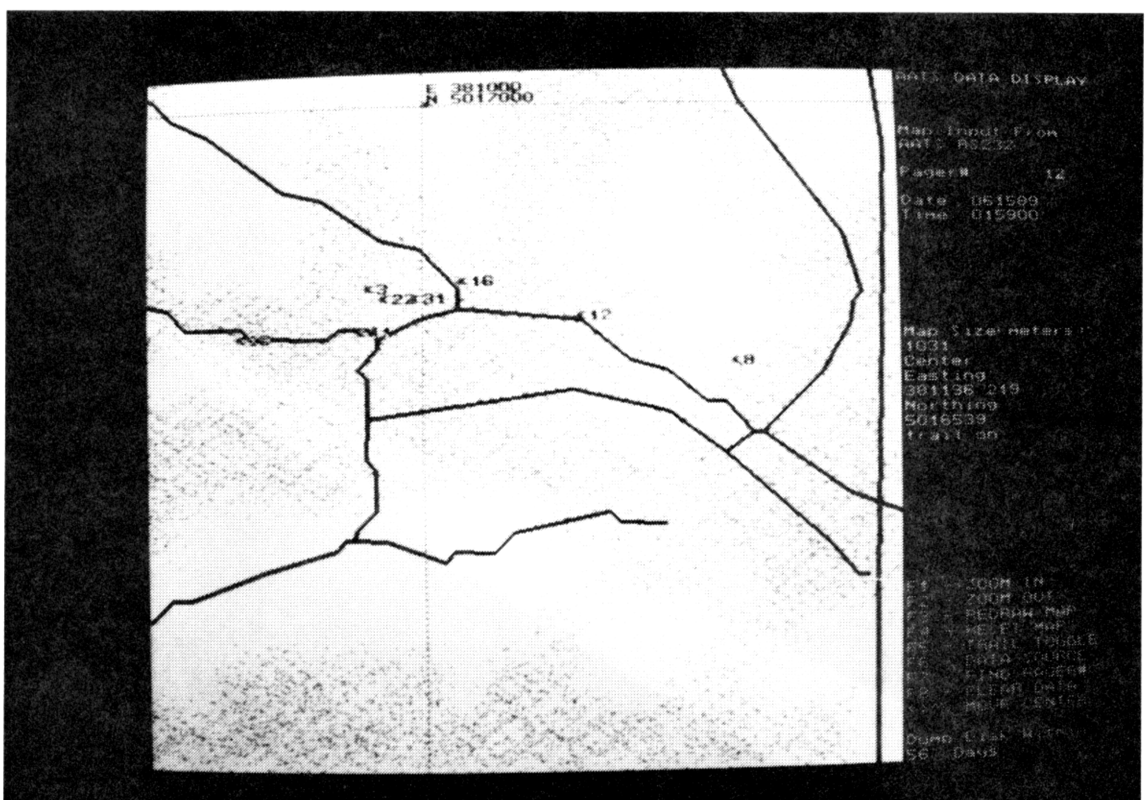

Figure 10. AATS Map Display of Detail in Forest Management Area

ware supplied with the tape system. Sixty days of AATS data can be transferred to the tape in under 30 minutes.

A map screen, using the same format and files as the CSPC, allows operator zoom, window positioning, and display of all pager positions. The map position source can be switched from the RS232 input to any AATS data file on the hard disk. The data from the current day's file can be examined interactively while the file is being updated in real time. Function keys control map source, operator selected zoom, map centering on a specific collar number, and colored position history trails [Figures 9 & 10].

A text display gives date, time, status, position, and temperature data, as well as map scale and center parameters. The size and position of the zoom window are also displayed when the zoom window is active. The minimum time before the disk is full and must be dumped to tape via the "QS" command from DOS is displayed on the text screen. This warning changes to a red display and the time changes from days to hours when the remaining time is less than 48 hours.

AATS DEPLOYMENT

The system was deployed in June 1989. Refinements to the retransmission link were made in July 1989.

Initial tests were done without a geodetic reference system in place, but position noise was computed to be from 45 to 85 meters (one standard deviation) at various static test sites using collars placed on stands.

Nine elk and ten cattle were tracked during the first phase of deployment. The elk collars had been built and installed three months before. The cattle collars were built and installed just prior to deployment. Ten deer collars were supplied, but not used in initial testing. Position reports from the cattle were easy to verify. The cattle remained in the same location for long periods and did not move when approached. Elk positions in the forest were verified by researchers with binoculars carefully approaching the animals on foot. It would have been difficult to find the elk at all without precise and timely position reports from the system.

CONCLUSIONS

The Automated Animal Tracking System has been successfully deployed at the Starkey Project. The system uses techniques for animal tracking that are new to wildlife management. AATS complements existing tracking techniques, geographic information systems, and research technologies in remote sensing, making possible new areas of wildlife study. The next step will be the integration of animal position data into current wildlife studies and the development of new methodologies using this technology.

ACKNOWLEDGMENTS

The authors would like to thank Jack Thomas, Larry Bryant, Glenn McLaughlin, and Floyd Snyder of the U.S. Forest Service for their support and hard work; John Curry and Steve Lilley of Internav for their interest and cooperation; and especially Jimmie Plentl, the AATS Program Manager at Tracor, for his support during every phase of this project.

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