Automated Animal Tracking Using Phase Interferometry

Nicholas Borchardt
Robert Hoffman
Adam Morris
Jordan O'Hearn
Jesse Rotman
Department of Engineering
Grand Valley State University
Grand Rapids, MI 49504
Email: borcharn@mail.gvsu.edu

Karl Brakora
Department of Engineering
Grand Valley State University
Grand Rapids, MI 49503
Email: brakorak@gvsu.edu

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When tracking small animals, researchers often rely upon low-powered beacon collars with limited functionality, usually emitting a simple pulse-CW VHF signal. These animal collars typically are tracked by the researchers using handheld directional antennas, and require the researcher to manually locate and record the position of the animals. In this paper, we will outline an automated tracking tower that can be deployed in the wilderness to constantly monitor the location of the desired tracking collars.

This paper details a student design of an expandable animal tracking system integrated into a field-deployable 20ft. tower. The receiver employs several phase-synchronized Software Defined Radios (SDRs) to implement a phase interferometric measurement of the signal's direction of arrival. Calibration and time synchronization between the individual channels of the receiver is achieved by synchronizing a white noise calibration signal. The system measures and stores the bearing, animal identification, and time of animal contacts. The system has been measured to be able to accurately determine the angle of arrival within 5 degrees of accuracy at a range of at least 0.75 miles. This automated tracking system can provide a much less labor-intensive method for researchers to monitor wildlife patterns and can be deployed in fairly remote locations for several weeks without requiring any human input.

Introduction

Extensive research has previously been conducted in the development of remote tracking networks to monitor animal life in the wild over a wide variety of environments. When tracking small animals, such as martens, researchers often rely upon low-powered beacon collars with limited functionality, usually emitting a simple pulse-CW VHF signal. These animal collars typically are tracked by the researchers using handheld directional antennas and require the researcher to manually locate and record the position of the animals. While GPS tracking collars have been developed to provide a simple and accurate means of locating an animal, the added power requirements of GPS make it impractical for use with smaller animals.

Several researchers have proposed automated tracking systems, which provide researchers a better method of collecting data, but these systems are often cumbersome, expensive, and inaccurate. One such system is the Automated Radio-Telemetry System (ARTS), which was built in order to track animals 24 hours a day, 7 days a week in the jungle. ARTS is comprised of directional antennas mounted on top of a 40-meter tower, which then connects to a receiving unit that transmits the collar data to an offsite server.[1]

While systems like ARTS can be very useful in animal tracking, they are expensive and lack portability, which is necessary when tracking animals that move over relatively large territories. In order to increase portability and decrease cost, a new low-cost automated tracking system was developed that can easily be transported and deployed by a two person team.

This new automated animal tracking system is comprised of a 20-foot tower, with three dipole antennas, separated by 120°, that connect to several phase-synchronized Software Defined Radios (SDRs) to implement a phase interferometric measurement of the signal's direction of arrival. By decreasing the size of the tower and utilizing a phase interferometric system, it was possible to lower the cost and weight of the system, while also maintaining excellent accuracy.

Tower Design

The tower is comprised of a steel base and fiberglass mast. The steel base provides a solid foundation while remaining cost effective and meeting all of the necessary functions. Fiberglass was chosen for the mast due to it being both stiff and strong in tension and compression when loads are applied axially.[2] Another benefit of using a fiberglass material is its electromagnetic invisibility, meaning that the fiberglass will not interfere with the reception of the analog signals being transmitted in the 148-152 MHz range. Other choice materials used were nylon rope, which was used for the guy wires, the nylon is UV resistance, and designed for outdoor applications. A rendering of the tower can be seen below in figure 1.

Figure 1: Automated Animal Tracking Tower

In order to maximize the portability of the tower, it was designed using a modular system that can be easily taken apart and reassembled. The fiberglass mast uses a telescopic system in which one pole slides into the other to reduce the size of the physical tower and allow for transport in the bed of a truck. Furthermore, the three-dipole antennas are affixed in an equilateral array around the top of the tower, but this array can easily be removed from the tower and transported separately. This ensures that the antennas will not be damaged or moved and allows for easy adjustment of the antenna spacing and angle.

The fiberglass tower slides into the center of the base and is locked in place using aluminum pins. Guy wires are attached at the top and mid points of the tower and the base is staked into the ground in order to ensure resilience to the environmental conditions the tower will be placed in.

Coaxial cable runs from the antennas through the center of the fiberglass mast and attaches to the receiving unit, which is affixed to the steel base and connected to three 65-Ah deep cycle batteries that will keep the unit running for 2 weeks without any human interaction. Both the receiving unit and the batteries are housed in sealed waterproof enclosures that protect against the environment and animals or humans that may unintentionally damage the electronics inside.

Direction Finding

While many systems like ARTS utilize directional antennas, which provide a simple and effective means of determining the angle of arrival of a signal, the method of tracking used in this project was phase interferometry. The choice to use interferometry was made because it is one of the most accurate methods to determine direction of arrival and it also allowed for the use of simple dipole antennas that are much less expensive than directional antennas that operate in the frequency range of 148 to 152 MHz.[3]

While directional antennas are typically very inexpensive, it is very difficult and costly to acquire directional antennas in the frequency range of 148 to 152 MHz because it falls between several important frequency bands. Because of this, there are very few suppliers of directional antennas in the animal tracking frequency range, which drives the cost to be very high. By utilizing interferometry, we were able to use dipole antennas, which reduced cost and simplified the tower design substantially, as it only required three antennas to operate properly.

Phase Interferometry is a form of direction finding that utilizes the phase difference between the signals received on several different antennas to determine the angle of arrival of the original signal. Every antenna array orientation requires a derivation to find the proper equation for the angle of arrival of the signal, which is described below for our system.

Given the generic equation for a waveform:

$$E = e^{-jk_x x} e^{-jk_y y} e^{-jk_z z}$$

Each antenna will have a different phase, which we can then subtract from one another to get the phase difference. This is useful because the phase is meaningless without a second, and in this case third, reference.

$$E_{13} = e^{-jk_x x_1} e^{-jk_y y_1} e^{-jk_z z_1} - e^{-jk_x x_3} e^{-jk_y y_3} e^{-jk_z z_3}$$
$$E_{23} = e^{-jk_x x_2} e^{-jk_y y_2} e^{-jk_z z_2} - e^{-jk_x x_3} e^{-jk_y y_3} e^{-jk_z z_3}$$

This can be simplified to (E_{12} and E_{23} follow the same derivation so only E_{13} is shown) :

$$\phi_{13} = k_x x_1 + k_y y_1 + \sqrt{k^2 - k_x^2 - k_y^2}\, z_1 - k_x x_3 + k_y y_3 + \sqrt{k^2 - k_x^2 - k_y^2}\, z_3$$

Given that $z_1 = z_2 = z_3$:

$$\phi_{13} = k_x(x_1 - x_3) + k_y(y_1 - y_3)$$

This leads us to using linear algebra to solve for the k values:

$$\begin{bmatrix} \phi_{13} \\ \phi_{23} \end{bmatrix} = \begin{bmatrix} (x_1 - x_3) & (y_1 - y_3) \\ (x_2 - x_3) & (y_2 - y_3) \end{bmatrix} \begin{bmatrix} k_x \\ k_y \end{bmatrix}$$

This can then be simplified to:

$$\begin{bmatrix} k_x \\ k_y \end{bmatrix} = \begin{bmatrix} \phi_{13} \\ \phi_{23} \end{bmatrix} \begin{bmatrix} (x_1 - x_3) & (y_1 - y_3) \\ (x_2 - x_3) & (y_2 - y_3) \end{bmatrix}^{-1}$$

We can then use the positions of each antenna to solve for k_x and k_y respectively:

$$\begin{bmatrix} k_x \\ k_y \end{bmatrix} = \begin{bmatrix} \phi_{13} \\ \phi_{23} \end{bmatrix} \begin{bmatrix} 0.409575 & 0.709405 \\ 0.81915 & 0 \end{bmatrix}^{-1}$$

We can then use this to solve for the original position of the signal:

$$\phi = \tan^{-1} \frac{k_y}{k_x}$$

$$\phi = \tan^{-1} \frac{1.4096\phi_{13} - 0.7048\phi_{23}}{1.2278\phi_{23}}$$

This takes into account the current antenna positions and allows the angular position of a collar to be calculated.

Automated Receiver Design

The automated receving unit is comprised of four RTL-SDRs and a raspberry pi that controls the four SDRs and analyses the data after it has passed through the recievers. The challenging aspect of a phase interferometric system is that is recquires phase coherence between each channel of the receiver in order to accurately determine the angle of arrival of the signal. Most phase coherent, multi-channel receivers are very expensive, well beyond the budget for this project, so a unique solution was identified using RTL-SDRs.

RTL-SDRs are a inexpensive receiver that are far from phase coherent, however, if the SDRs are fed by a common clock, they become phase stable. This means that while the receivers are not all at the same phase, they all maintain the same relative phase to each other while they are receiving data. These SDRs cannot be phase coherent because the nature of USB communcation does not allow for synchonous communication between multiple receivers, making each receiver initialize at a different time.

It has been proven, however, that by calibrating the channels with a common white noise source, the phase offset of each receiver can be determined as long as the receivers are not reinitialized. This means that all of the SDRs must be sent a common white noise source for a calibration period and then switch to the antennas within the same receiving cycle. As long as the tuners are not retuned to a different frequency, they will maintain phase stability for a relatively long time.

The receiver used in this project was a 3+1 coherent system from coherent-receivers.com.[4] They produce all the required modules, as well as modify existing RTL-SDRs, to ensure phase coherence between the channels of the receiver. Three of the SDRs are used as the actual receivers that are connected to the antennas, while the fourth SDR is used as a master that supplies a common clock and controls the noise source and antenna switch that are required for coherent receiving.

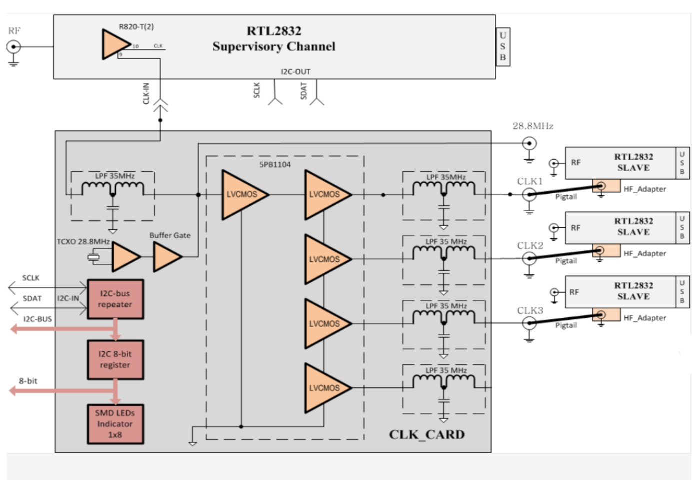

Figure 2: 3+1 Receiver System Diagram[3]

As stated previously, this system is not truly phase coherent, but is merely phase stable with modifications that allow us to calibrate the receivers, which provide a reasonable amount phase coherence. While other more expensive receivers can produce more accurate results, a system like this allows for a strong balance between budget and accuracy.

Digital Signal Processing

By far the most difficult part of an automated animal tracking system of this nature is the signal processing required in order to accurately pick out a VHF beacon from up to 0.75 miles away. Because these collars do not contain any data, the only way to determine that a signal exists is to ensure that the pulse width is correct. This can lead to many sources of error, especially at long distances. Any signal that has a similar length and is in the right frequency band can interfere with the received signal.

The Digital Signal Processing (DSP) for this system can be broken down into three main components, receiver calibration, signal detection, and collar bearing calculation. Calibration is performed in order to determine the inherent phase difference between the SDRs and account for the phase difference in the final angle of arrival calculations. In order to calibrate the system, noise is collected from the included noise card and then the noise signal captured by each SDR is cross correlated in order to calculate phase discrepancies between each SDR.

For signal detection the system takes FFTs of 5ms sections of the incoming data, then implements a band pass filter in each channel around the tolerance of the signal frequency, and next the max signal amplitude within that band is recorded. Once the peaks of each FFT are found the peaks are analyzed in order to identify the 20ms signal by finding 4 peaks in a row that fall in the same frequency bin. Once the signal is identified, a second FFT is taken over the period of time that the signal was received, and the phase data from this FFT is used to determine the bearing of the collar using the equation described previously. After finding the phase of the signal on each channel, the system must adjust the phase difference between the signals by the phase offset found in the calibration step. After this process the collar bearing can be saved to an SD card and the process can begin again.

Test Results

The system was tested outdoors with collars placed at measured angles around the tower at a distance of approximately 50 yards. Collars were placed at known angles of 65 degrees, 215 degrees, and 305 degrees in order to provide a broad range of angles around the tower.

After several tests at each angle, the tower was able to calculate the angle of arrival of the tracking signals within 5 degrees. When measuring the angle of arrival of the signal from the known collar locations of 65 degrees, 215 degrees, and 305 degrees, the system calculated an average angle of arrival of 67.99 degrees, 213.85 degrees, and 303.64 degrees, respectively.

Testing was also performed in order to confirm that the system could sense collars at a distance of 0.75 miles. Unfortunately, it was discovered during testing that one of the coaxial connectors had been damaged and did not have a proper connection between the receiving unit and the antenna. Because of this, one channel of the receiver was not able to identify a collar signal, and the system was not able to determine the angle of arrival of the collar at 0.75 miles. However, the two receiver channels that were not damaged were able to pick up the collar signal, leading us to believe that the system can sense and calculate the direction of arrival of a collar at a distance of 0.75 miles.

Conclusion

As described in this paper, the use of an affordable and easily deployable tracking tower can greatly aid in tracking low power VHF animal collars. By implementing a system using low-cost RTL-SDR's and phase interferometry, researchers can reduce the cost and manpower required to gather data on the movement patterns of small animals in the wild. Although testing could not be completed on all channels at 0.75 miles, a system that is accurate within 5 degrees at up to 0.75 miles will allow for researchers to determine the forest stands that wildlife move between and the general habitat that they live in.

Biographical Information

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