Real-Time Location Estimation System for Wild Animals

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Abstract

It is a very serious problem that many kinds of development projects threaten the ecosystem of wild animals. Before and after the projects, it is required to assess the change of the ecosystem. An animal location estimation system has been developed for this purpose. The system consists of small transmitters which are attached to the wild animals, and receiver stations with Yagi-Uda antennas. Then the stations receive the signals from the animals and estimate the angle of arrival of the signals by rotating the antenna. The drawback of this conventional system is that the rotation of the antenna takes long time and the tracking accuracy is insufficient. We developed a new system using array antennas and signal processing technology. This paper presents the system configuration, calibration technique, and the field test results of the system.

Keywords: Wild animal, angle of arrival estimation, array signal processing.

1. Introduction

It is a very serious problem that many kinds of development projects, e.g. the river improvement, threaten the ecosystem of wild animals. Before and after the projects, it is necessary to assess the impact to the ecosystem. Telemetry systems have been used for tracking the movement of the animals. A small transmitter is attached to a wild animal. In the conventional system [(1)], more than one receiver stations with Yagi-Uda antennas are installed in the measurement field and the stations find the directions of the animal by rotating the antenna to search for the strongest direction of the signal. After the measured data are collected, the location of the animal is estimated by the triangulation.

The targets are usually the small wild animals, e.g. raccoon dogs, rabbits, and fishes. The conventional system works well for these targets. However, it is more difficult for the conventional system to track the fast-moving animals like birds, as it takes more than two minutes to rotate the antenna to search for the direction, and obviously the target animal may move so much during the period.

This paper presents a real-time location estimation system for wild animals. We have aimed at a fast estimation of the location, and we utilize an array signal processing technique for the real-time angle of arrival (AOA) estimation. We first explain the system design, and then describe the detail of the receiver station. Finally, the results of the preliminary experiment are presented to verify the operation of the system.

2. Measurement Environment

The telemetry system is used in the following fields:

- Grassland
- Forest
- River (Fig. 1)

Fishes and birds are the target animals at the rivers. In case for Fig. 1, birds live in sandbanks. The measurement field is sized about several hundreds square meters as these target animals do not move long distances.

In some of the fields, there are a lot of obstacles such as the vegetation. The signal is scattered, diffracted, and reflected by the vegetation, as well as is transmitted through it [(2)]. In case, the environment is suffered from the multipath propagation.

Fig. 1. Chikuma river: an example of the test fields.

3. System Design

3.1 Overall System Configuration The proposed system has the following characteristics.

- A small transmitter is attached to a wild animal.
- More than one receiver stations which estimate the angle of signal arrival are installed in/around the measurement field.
- Wireless LAN connects the receiver stations and a data collection PC. The position is estimated by the triangulation.
- Radio frequency of 144 MHz is used, due to the availability of the commercial transmitters [(3)], and due to the relatively low transmission loss through water and vegetation.

Fig. 2 shows the schematic view of the systems, and the signal/data flow of the system is listed as follows:

(1) The transmitter emits the signal.
(2) The receiver stations detect the signal.
(3) The receiver stations estimate the angle of arrival (AOA).

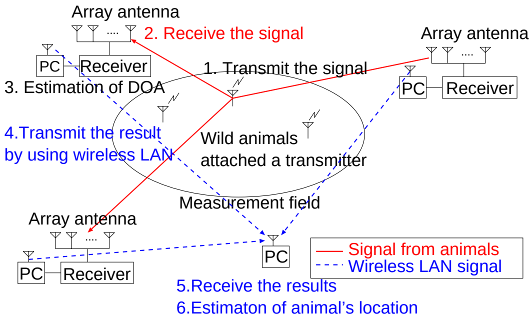

Fig. 2. Proposed location estimation system for wild animals.

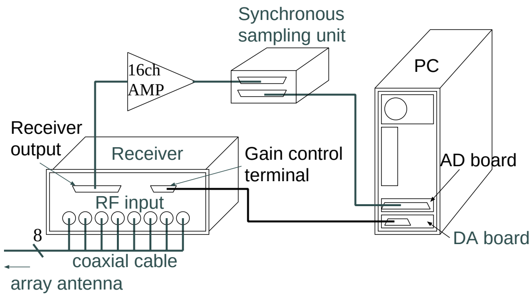

Fig. 3. Receiver station.

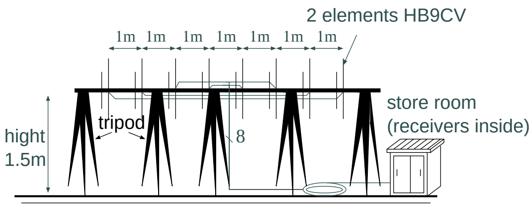

Fig. 4. Configuration of array antenna.

(4) The receiver stations send the AOA estimation result to the data collection PC via wireless LAN.
(5) The data collection PC receives the AOA results.
(6) The data collection PC estimates the location of wild animals by triangulation.

By now, a receiver station has been built and tested.

3.2 Transmitter A miniature transmitter, model MBFT-7A manufactured by LOTEK [3], is considered for the system. This transmitter emits a pulsed signal with the period of 2 s and the duty ratio of 6×10^{-3} to save battery power. The emission frequency is in 144 MHz band.

3.3 Receiver Station A receiver station consists of an array of antennas, an 8 ch I/Q receiver, a 16 ch baseband amplifier, a synchronously sampling 16 ch A/D board in a PC, and AOA estimation software, as depicted in Fig. 3.

3.3.1 Array antenna An 8-element uniform linear array antenna has been constructed as shown in Fig. 4. The element spacing is 1 m, which is slightly smaller than 0.5 wavelength. As an array element, HB9CV type antenna is used. This type of the antenna is commonly used for amateur radio. This antenna consists of two dipole antennas to exhibit a unidirectional property. A unidirectional antenna is preferred as the multipath from the objects behind the array can be suppressed.

3.3.2 Receiver A receiver is equipped with 8 RF channels. This receiver has a common local oscillator because AOA estimation algorithm requires the phase difference between the channels. The receiver converts the RF signal at 144.700 – 144.900 MHz down to DC−100 kHz, and outputs the I/Q signal. As the specification of the receiver, input signal level should be from −50 dBm to −100 dBm, and output signal level is below 250 mV.

3.3.3 Baseband Amplifier Although the output signal voltage of the receiver is below 250 mV, the maximum input voltage range of A/D converter is ±10 V. Therefore, the amplifier is needed for the full use of the A/D converter quantization bits. A 16 ch precise baseband amplifier has been fabricated. The gain of the amplifier is designed as 39. An operational amplifier OP37G, which has wide-band, low noise and precision characteristics, has been used.

3.3.4 A/D Converter The A/D board model AD681-PCI manufactured by Microscience has been used to sample the output of the baseband amplifier [4]. This board has 16 channels of analog input with 14 bit quantization. The input voltage range is ±10 V, as mentioned in the previous subsection. Although this board has 16 ch analog input, it uses a multiplexer. Therefore, a synchronous sampling unit model SHU-516, which is a 16 ch sample-and-hold unit, is attached to the A/D board. The sampling rate is about 45 kHz.

3.3.5 AOA Estimator Among several types of AOA estimation algorithms [5], MUSIC (MUltiple SIgnal Classification) algorithm was selected [6]. MUSIC algorithm is a sub-space based super-resolution AOA estimation algorithm.

The received signal $\mathbf{x}(t)$, M dimensional vector, is modeled as

$$\mathbf{x}(t) = \mathbf{A}\mathbf{s}(\mathbf{t}) + \mathbf{n}(\mathbf{t}), \quad (1)$$

where M is the number of the array element,

$$\mathbf{A} = [\mathbf{a}(\theta_1) \quad \cdots \quad \mathbf{a}(\theta_L)] \quad (2)$$

is an $M \times L$ array response matrix, where L is the number of arrival signals,

$$\mathbf{a}(\theta) = \left[1 \quad \exp\left(-j\frac{2\pi d \sin\theta}{\lambda}\right) \quad \cdots \quad \exp\left(-j\frac{2\pi(M-1)d\sin\theta}{\lambda}\right)\right]^T \quad (3)$$

is an array response vector for the arrival angle of θ measured from the broadside of the array,

$$\mathbf{s}(t) = [s_1(t) \quad \cdots \quad s_L(t)]^T \quad (4)$$

is an L dimensional signal waveform vector, and $\mathbf{n}(t)$ is an M dimensional additive white Gaussian noise vector which satisfies

$$E[\mathbf{n}(t)\mathbf{n}^H(t)] = \sigma^2\mathbf{I} \quad (5)$$

where σ^2 is average noise power.

The covariance matrix of $\mathbf{x}(t)$, $\mathbf{R}_x$ is eigendecomposed as

$$\mathbf{R}_x = E[\mathbf{x}(t)\mathbf{x}^H(t)] = \mathbf{E}\mathbf{\Lambda}\mathbf{E}^H, \quad (6)$$

where the eigenvalue matrix is

$$\mathbf{\Lambda} = \mathrm{diag}(\lambda_1, \ \cdots, \ \lambda_L, \ \sigma^2, \ \cdots, \sigma^2), \quad (7)$$

where

$$\lambda_1 > \cdots > \lambda_L > \sigma^2, \quad (8)$$

and the eigenvector matrix $\mathbf{E}$ satisfies

$$\mathbf{E}\mathbf{E}^H = \mathbf{I}. \quad (9)$$

The MUSIC spectrum $P_{\mathrm{M}}(\theta)$,

$$P_{\mathrm{M}}(theta) = \frac{1}{|\mathbf{a}^H(\theta)\mathbf{E}_{\mathrm{n}}|^2}, \quad (10)$$

where noise subspace matrix $\mathbf{E}_{\mathrm{n}}$ is

$$\mathbf{E}_{\mathrm{n}} = [\mathbf{e}_{L+1} \quad \cdots \quad \mathbf{e}_M]. \quad (11)$$

$P_{\mathrm{M}}(\theta)$ is the inverse of the projection of the array response vector to the noise subspace, takes its peaks at θ_l, $l = 1, \ \cdots, \ L$.

If the measurement field is suffered from multipath, the spatial smoothing preprocessing (SSP) scheme should be used to decorrelate the multipath components [7]. In SSP, K-element subarray ($K < M$) is chosen among M-element array. The choice of the subarray is $N = M - K + 1$. Instead of using $\mathbf{R}_x$, $M \times M$ correlation matrix, the following $\bar{\mathbf{R}}_x$, $K \times K$ averaged correlation matrix, is used in MUSIC.

$$\bar{\mathbf{R}}_x = \frac{1}{N}\sum_{n=1}^{N} E[\mathbf{x}_n(t)\mathbf{x}_n^H(t)], \quad (12)$$

where

$$\mathbf{x}_n(t) = [x_n(t) \quad \cdots \quad x_{n-1+k}(t)]^T \quad (13)$$

is the output signal of n-th subarray.

4. Receiver Calibration

In the real receiver, the output is varied from the ideal value. For example, error of cable length, impedance mismatch, receiver gain, amplifier gain, A/D converter sensitivity, etc., are the possible factors. Therefore, the output value of the real receiver $\tilde{\mathbf{x}}$ is modeled as

$$\tilde{\mathbf{x}}(t) = \tilde{\mathbf{A}}\mathbf{s}(t) + \mathbf{n}(t), \quad (14)$$

where $\tilde{\mathbf{A}} = \mathbf{K}\mathbf{A}$ and $\mathbf{K}$ is an $M \times M$ diagonal error matrix which represents all the linear the impairments of the receiver.

In the calibration process, we estimate $\mathbf{K}$ and the calibration matrix $\mathbf{C} = \mathbf{K}^{-1}$ is multiplied to cancel all these impairments [8].

In the calibration process, we transmit the signal from the known direction θ_0, and estimate $\mathbf{K}$. The m-th diagonal component of $\mathbf{K}$ is obtained as

$$K_m = \frac{\alpha_m}{\alpha_0}\exp\left(j(\phi_m - \frac{2\pi(m-1)d\sin\theta_0}{\lambda})\right), \quad (15)$$

where α_0 is the ideal amplitude response, α_m and ϕ_m are the measured amplitude and phase of m-th channel.

Fig. 5. Test Field: PWRI.

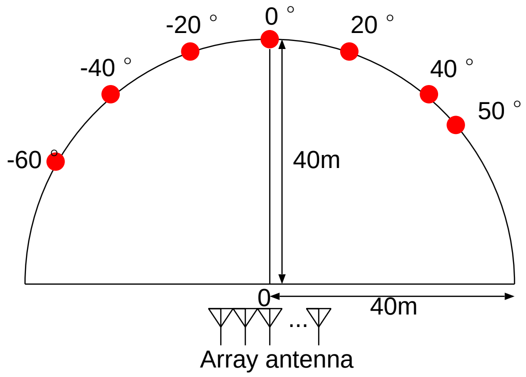

Fig. 6. Arrangement measurement

Table 1. AOA estimation results.

Tx direction (degree)	MUSIC Estimation (degree)	MUSIC with SSP Estimation (degree)
-60	-52.91	-52.87
-40	-39.63	-39.64
-20	-17.59	-17.82
20	18.14	18.06
40	38.00	37.44
50	48.64	48.03

5. Field Test

5.1 Measurement Condition A field test was conducted in Public Works Research Institute (PWRI), Tsukuba, Japan. We measured in the open ground as shown in Fig. 5.

We set 7-element array antenna, as one RF channel of the receiver was broken in the test. We used an amateur radio transceiver to transmit the CW signal, instead of the miniature pulsed transmitter. We moved the transmitter in 7 directions, i.e., -60, -40, -20, 0, 20, 40, and 50 degrees, as shown in Fig. 6. The distance between the transmitter and the center of the array antenna was 40m.

5.2 Measurement Results Measurement results are summarized in Table 1. 0 degree measured data were used as the calibration data. It is found that the error between actual angles and estimated angles is less than 3 degree except for -60 degree. In -60 degree case, the

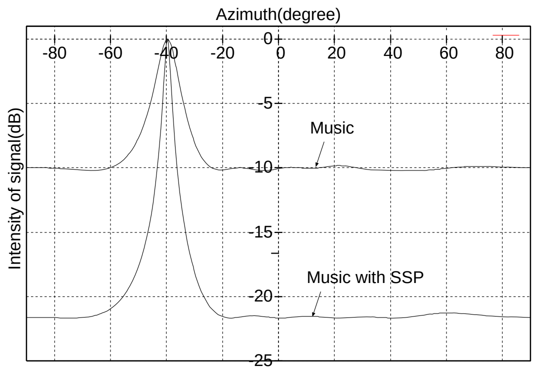

Fig. 7. MUSIC spectra with and without SSP for −40 degree case.

larger error seems to be due to the directivity of HB9CV antenna. An HB9CV antenna is with the 3 dB beamwidth of $\pm 50^\circ$, and it is not suitable for estimating the angle outside this range.

Fig. 7 compares the MUSIC spectra with and without SSP. With SSP, the size of the subarray is 6-element. Although the peak positions are not so different, the sharp peak is observed for the case with SSP. The reason should be investigated for the future, but it seems that the fluctuation of the positions and the directivity of the array elements are averaged and randomized, and the error is reduced.

6. Conclusion

A real-time location estimation system for wild animals has been developed. In particular, a receiver station was fabricated, and it was tested and verified in the field.

A few important tasks remain for the future work:

(1) Integration of the whole system, i.e. more receiver stations to be developed.

(2) Consideration of the multipath environment due to the trees, vegetation, and terrain.

(3) Size reduction of the array antenna for the realistic installation. Higher frequency may be considered.

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