Using underwater coded acoustic telemetry for fine scale positioning of aquatic animals

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Abstract

Measurements of aquatic animal movements, activity, and energetics in nature have always been technologically challenging. In many species around the world, detailed movement and activity information is urgently required for a variety of reasons. Issues related to fishing pressure, habitat degradation, pollutants, and responses to environmental change are just a few of the many applications that require knowledge of the temporal and spatial movement patterns of aquatic animals.

Here we describe the development and implementation of a new multi-receiver positioning system (VPS–VEMCO Positioning System) that can be used in a variety of biological applications to study the behavior of aquatic animals in nature. VPS is more suited to a larger variety of applications compared to existing positioning systems that are constrained by cost and equipment deployment limitations (e.g. wire connecting hydrophones). To date, VPS has been successfully used in small (3 receivers covering 2500 m^2) and large area studies (tens of kilometers^2) in lakes, rivers and ocean environments. We discuss the design and specifications of VPS, the factors that influence positioning accuracy, and some examples of VPS study designs.

Keywords: *acoustic telemetry, coded transmitters, fine scale positioning, VPS, VEMCO.*

Introduction

The need to address increasingly complex questions about the behaviour and ecology of aquatic animals has led to advances in acoustic telemetry in recent years that allow collection of data previously inaccessible to scientists [1, 2].

Traditional active tracking methods, while providing fine-scale movement data and high positioning accuracy, are time consuming and labour intensive [2], and are unsuitable for large sample sizes and coverage of large geographic areas. Traditional passive (presence/absence) tracking, although it provides the ability to track multiple undisturbed individuals simultaneously and can cover large geographic areas, does not typically provide the spatial resolution required to answer questions about habitat use, resource utilization, animal interactions, and small-scale movement patterns [3].

The VEMCO Positioning System (VPS) is an autonomous fine-scale positioning system that addresses some of the issues with traditional active and passive tracking methods. The system's positioning algorithms are derived from those of its predecessor, the Vemco radio-acoustic positioning (VRAP) system [1,4]. The algorithms are extended to work with three or more receivers, allowing for virtually unrestricted geographic coverage [1]. The largest array to date has comprised over 150 VR2W receivers, covering an area of more than 15 km^2. The VPS algorithms work with receivers that do not have synchronized clocks [5]. Therefore, there is no requirement for radio links, cables, or base stations. Remote and unattended operation for months at a time up to one year or more is possible due to long battery life [6]. The system is non-real time, so receivers must be retrieved and data post-processed to obtain animal positions.

The use of coded transmitters allows for positioning of multiple animals on the same transmission frequency simultaneously. Temporal resolution of positioning is of the order of minutes for an individual animal, and spatial resolution is typically in the 5-15 m range, although accuracy can vary significantly from study to study and over time within a single study. The VPS uses standard autonomous receivers and standard transmitters, so no special equipment is required. The VPS provides two-dimensional calculated positions. Horizontal position data can be augmented with information from sensor tags carried by the animal being tracked, such as depth, temperature, or acceleration.

Materials and Methods

Theory of Operation

The VPS uses the technique of time-difference-of-arrival (TDOA), or hyperbolic, positioning. This is the same technique that was used in the LORAN-C navigation system [7], and is currently used for positioning mobile phones [5]. The TDOA positioning technique is based on the calculation of range differences between a transmitter and two stationary receivers. Measured differences in arrival times of a transmitted signal at a stationary receiver, Ra, and a second receiver, Rb, are converted to range (distance) differences using the speed of sound in water. In 2D a given range difference places the source of the transmitted signal at a location along a specific hyperbola, as shown in Fig. 1. The addition of a third receiver provides a second range difference, generating a second hyperbola. The position of the transmitter is known if the two hyperbolas intersect at a single point, as shown in Fig. 2.

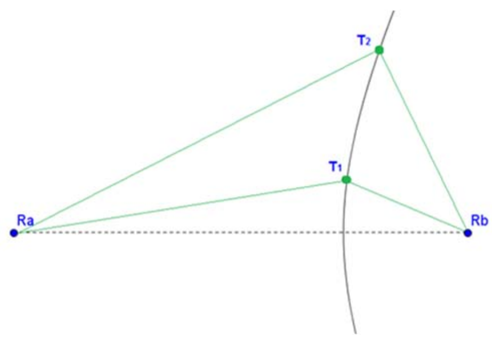

Fig.1: Locus of range difference points is a hyperbola. T1, T2 are transmitters with the same range difference to fixed receivers Ra, Rb.

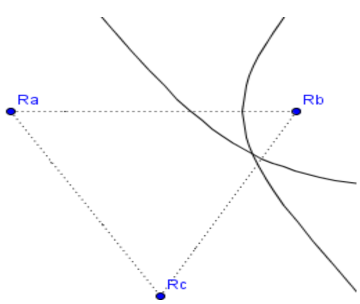

Fig. 2: Range difference information from 3 receivers generates 2 intersecting hyperbolas that identify the location of the transmitter.

Deployment

A typical VPS deployment consists of three or more receivers arranged in a regularly spaced pattern of equilateral triangles or squares. Stationary transmitters, called synctags, are used to correct for receiver clock drift and maintain system time synchronization. These synctags are placed throughout the array, typically colocated at each receiver station (Fig. 3). A second group of stationary transmitters, called reference tags, is also placed throughout the VPS array. These tags are matched to the output power of the animal tags in the system, and are used to assess the detectability and positionability of animal tags in different areas of the array. They are also used, along with the synctags, to estimate the error performance of the VPS array.

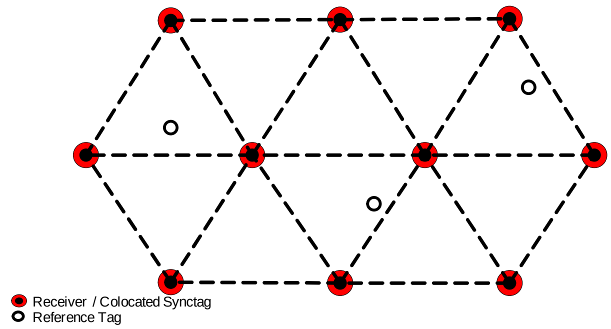

Fig. 3: Typical triangle-based VPS array layout.

Time synchronization

After an autonomous receiver's clock is set during initialization with a PC, the clock begins to drift by up to 4 seconds per day [5]. The arrival time differences used as inputs for the TDOA positioning algorithm are of the order of milliseconds, and therefore their calculation requires time synchronized receiver clocks.

The clock skew (offset between receiver clocks) is determined for each pair of receivers in the system using synctag detection times. Because synctag transmissions occur at random intervals, the pattern of synctag detections at a pair of receivers can be uniquely matched over time, as shown in Fig. 4.

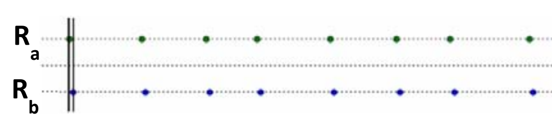

Fig. 4: Pattern of detections of a single stationary synctag at a pair of receivers, Ra & Rb, over time.

Figure 4 demonstrates that detections of the same synctag line up when the detection times on receiver Ra are shifted by the distance between the vertical lines. This distance is the clock skew. Clock skew between receivers changes throughout the deployment period, and therefore time synchronization between receiver clocks is accomplished on a continual basis by the algorithm.

Results

A number of authors have tested the error performance of the VPS. The system has been compared to active tracking and the VRAP system [2, 6], and the spatial distribution of positioning probability and positioning error has been analyzed in some detail [8]. Other authors have reported on VPS error performance based on the scatter of calculated positions for stationary synctags [9]. Table 1 lists some examples of the reported positioning error in VPS arrays.

Study	Reported Error	Comments
Andrews et al 2011 [6]	+/- 1.8 m	4-receiver VPS array
	+/- 1.5 m	3-receiver VPS array
Roy et al 2014 [8]	3.3m +/- 3.3 m	Average error of data filtered by HPE[1] <= 15
	2.4 m +/- 2.1 m	Average error inside array (filtered data)
	4.2 m +/- 4.0 m	Average error outside of array (filtered data)
Espinoza et al 2011 [2]	2.64 m +/- 2.32 m	Average error of a stationary transmitter placed at several locations inside array
	4.07 m +/- 2.46 m	Average error of moving transmitter inside array (data filtered by HPE[1] <= 10)
	4.12 m +/- 2.68 m	Average error of moving transmitter outside of array (filtered data)
Scheel and Bisson 2012 [9]	5.2 m	Average error of data filtered by HPE[1] <= 20

Table 1: List of reported position error with VPS.

[1]HPE (Horizontal Position Error) is a unit less, relative measure of error potential provided for all positions calculated by the VPS.

Discussion

To date 168 VPS studies have successfully been conducted in numerous aquatic environments.

Conclusions

VPS is an invaluable tool for the study of fine scale aquatic animal movements. VPS research will focus on improving the spatial and temporal resolution, and providing a real-time VPS solution.

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