PROCEDURAL OPTIMIZATION AND MEASUREMENT OF PASSIVE ACOUSTIC SENSOR NETWORKS FOR ANIMAL OBSERVATION IN MARINE ENVIRONMENTS

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To myself,

Perry H. Disdainful,

the only person worthy of my company.

ACKNOWLEDGMENTS

I want to “thank” my committee, without whose ridiculous demands, I would have graduated so, so, very much faster.

ABSTRACT

Static Observation Networks (SONs) are often used in the biological sciences to study animal migration and habitat. These networks are comprised of self-contained, stationary sensors that continuously listen for acoustic transmissions released by sonic tags carried by individual animals. The transmissions released by these tags carry serial identification numbers that can be used to verify that a particular individual was near a given sensor. Sensors in these networks are stationary; therefore, sensor placement is critical to maximizing data recovery. Currently, no open-source automated mechanism exists to facilitate the design of optimal sensor networks. SON design is often governed by loose "rules of thumb" and "by eye" readings of low resolution bathymetric maps. Moreover, there is no standardized method for evaluating the efficacy of a SON. In this paper, we present a system which takes advantage of high-resolution bathymetric data and advanced animal modeling to provide optimal network designs. Our system also allows for statistical analysis of existing network configurations in order to create efficacy-metrics that can be used to evaluate arbitrary network configurations.

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CHAPTER 1
INTRODUCTION

Static Acoustic Observation Networks (SAONs) are often used in the biological sciences to study aquatic animal migration and habitat. These networks are comprised of self-contained, stationary sensors (hydrophones) that continuously listen for acoustic transmissions released by sonic tags carried by individual animals. The transmissions released by these tags carry serial identification numbers that can be used to verify that a particular individual was within detection range of a specific sensor at a given time. Acoustic networks are relatively inexpensive (compared to GPS/VHF Radio/Satellite tags). The primary goal of any tracking study is to obtain a high number of high quality data points (relating individual animals to space and time) in order to gain some insight into animal behavior. SAONs provide a way to generate a large volume of data points at low cost, resulting in cost-efficient data points. However, unless these data points are captured, the cost efficiency of SAONs is lost. Within SAONs, data capture rates are highly dependent upon the chosen locations for sensors within the study area. The malplacement of sensors (in locations that interfere with the reception of data or where no tagged individuals are present) leads to low data returns, wasted resources, and diminished cost-efficiency. We present an application that takes advantage of high resolution bathymetry, flexible behavioral modeling, and simplified acoustic propagation models to maximize the data recovery of a SAON. Our application provides a reproducible, customizable, and distributable method for generating optimal sensor placements and analytical network metrics.

1.1 Static Acoustic Observation Networks

1.1.1 Sensor Assembly

[Diagram of rigging] SAONs are composed of stationary rigs that are responsible for maintaining the chosen location for a sensor. Because positional data is interpolated from the position of nearby sensors, it is important that sensors are deployed accurately and maintain their position throughout the entire experiment[9]. This is best accomplished by attaching sensors to permanent emplacements (such as a rigid metal frame driven into a rocky substrate) that will resist substantial amounts of force (such as strong currents and curious animals). However, when it is not always possible to create such permanent emplacements (perhaps due to regulation or extreme depth), more creative approaches are called for. A popular rigging consists of an acoustic sensor attached to a length of wire/rope with a strong float on one end, and a substantial ballast with an acoustic quick release on the other[9]. Such a rig can be dropped in the ocean and allowed to sink to its desired location. Obviously, various situations will require different rig designs and may contribute significantly to network costs (acoustic releases cost approximately $2700 per piece).

1.1.2 Sensor Deployment & Recovery

The labor required for sensor deployment and recovery depends on the design of the sensor assembly. Creating a permanent, rigid emplacement for a sensor can require multiple divers, special equipment, and hours of underwater elbow grease. Recovery of a permanent, rigid emplacement will most likely require a diver to physically remove the sensor from its emplacement. Deployment of ballast/float assemblies can be as simple as dropping the assembly overboard. Recovering a ballast/float assembly simply requires signaling the acoustic release with a hydrophone and allowing the buoy to carry the sensor assembly to the surface.

1.1.3 Tag Deployment

The most challenging and time consuming task in animal tracking is the physical deposition/implantation of tags on/into the individuals to be tracked. In the case of marine tracking, this can be particularly challenging as animals must be located, captured, tagged, and released relatively quickly to avoid over-stressing the animals. Improper handling/release of an animal can result in its death and the loss of a tag. All telemetry technologies will eventually require interaction with the individual to be tracked, and acoustic tracking is no different.

1.1.4 Comparison of Technologies

1.1.4.1 Very High Frequency Radio

Very High Frequency radio (VHF) tracking involves attaching a VHF transmitter to an animal, and then using a VHF antenna and receiver to receive transmissions. VHF transmissions have effective ranges on the order of tens of kilometers. Transmissions from VHS devices do not generally contain positional data, but instead serve as a means to estimate the distance and direction of a VHS device. Positional data is derived by noting the direction and strength of a signal from several different observational positions, and estimating the transmitter's position by triangulation[6]. In a marine setting, VHF observation is generally performed from a plane or boat[1].

1.1.4.1.0.1 Sateallite/GPS Satellite and GPS tracking are distinct but related technologies that rely on a network of satellites (either ARGOS or GPS, respectively) to compute the positional data of a tag. GPS tags rely on the GPS network of satellites to triangulate a tag's three dimensional position. GPS telemetry may be stored on-board a tag (requiring later retrieval), or transmitted via satellite to a remote server[6]. Satellite tags operate by transmitting messages to the ARGOS satellite system, which computes a tag's position by observing the Doppler effect on a tag's transmission[2]. Because the telemetry from satellite tags is transmitted back to remote servers, data recovery is automatic. Both technologies have fairly poor penetration into the ocean, and so GPS/Satellite transmissions generally occur only when an animal is near the surface of the ocean. This can lead to data sets with large spatial/temporal gaps between detections. Additionally, neither technology is desirable for observing animals that reside at significant depths. Due to the high cost of Satellite/GPS technology, studies using this technology generally have very small sample sizes.

1.1.5 Advantages of Acoustic Networks

After initial deployment, SAONs require no maintenance and incur no operating costs (unlike satellite and VHF radio technologies). This means that SAONs can operate around the clock, and in conditions that would otherwise make it unsafe/impossible for field researchers to track animals (e.g. in a storm)[9]. However, it is necessary to retrieve the acoustic sensors at the end of the study in order to recover data[9]. Finally, SAONs allow for passive animal monitoring, removing the potential disruption of natural behavior caused by active tracking (e.g. aircraft/boat noise/shadow scaring animals)[9]. SAONs also function at greater depths than satellite/VHF-based systems. Because the reception of acoustic transmissions (by acoustic sensors) occurs at the resident depth of the target species, an acoustic tag's transmission need not penetrate to the surface to be detected (unlike Satellite and GPS based systems).

1.2 The Cost of Data

1.2.1 Cost of Alternative Technologies

SAONs are relatively cheap, with acoustic sensors costing approximately $1300, and acoustic tags costing approximately $330 each. Moorings for acoustic receivers can be significantly more expensive, with acoustic releases costing slightly more than twice the cost of a receiver. However, these costs are still significantly more affordable than satellite-based tags and collars, which cost upwards of $6000 each. Additionally, recurring service fees and per-transmission charges may apply to data transferred over the satellite network. A seemingly cheaper alternative is the VHS radio tag, which costs about $??? each, but requires active monitoring to obtain each data point. The cost of paying for vehicles(boats/planes) and crews to periodically collect locational data will significantly outweigh any initial cost savings.

Table 1.1: Cost Summary of Alternative Technologies

Technology	Tag	Sensor	Operating Cost
VHF Radio Tag	$300	$???	Agents & Transport
Satellite Tag	$3000-$5000[3]	$0	Service fees
Acoustic Network	$330	$1300	$0

1.2.2 Operating Costs

While SAONs require no maintenance to operate, both Satellite and VHF based systems can incur operating costs while deployed. Satellite tags will require very little maintenance (precluding animal mortality), but satellite network operators may charge for access to and transmission over their network[3]. VHF systems require little maintenance, but do require active field work in order to obtain positional information. Because a tag's location is interpolated from observations of its VHS signal from multiple locations, it is necessary for a field agent to routinely collect these observations to obtain telemetry data. VHF networks have perhaps the highest operating cost, requiring a salary for one or more field agent(s) and transportation costs (renting a boat/plane). The operating costs for each technology should be included in the total cost of data collection, and subsequently the cost effectiveness of each solution.

[http://www.wildlifetracking.org/faq.shtml] [http://www.lionconservation.org/lion-collars.html] [http://www.africat.org/projects/radio-collars-for-lions]

VR2's cost $1.5k each, tags cost $350 each. http://www.gulfcounty-fl.gov/pdf/882532513025603.pdf

1.2.3 Cost Efficciency

Table 1.2: Lifespan & Total Expected Transmissions

Technology	Model	Transmit Period	Expected Lifespan	Expected Transmits
VHF Radio Tag	Telonics FIS-550	1s	76 days	273,600
Satellite Tag	Telonics ST-18	60s	117 days	168,480
Acoustic Tag	Vemco VR-13	90s	1,135 days	1,089,600

Should be a caption

http://vemco.com/products/v7-to-v16-69khz/ http://www.wildlifetracking.org/faq.shtml http://www.telonics 18/ http://www.mrcmekong.org/assets/Publications/Catch-and-Culture/catchmar02vol7.3.pdf

1.2.4 Quality of Data

Data fusion for better localizations.

1.3 State of the Art

1.3.1 "Rules of Thumb for Sensor Placement"

Heuple

1.3.2 Existing Metrics

1.3.3 Data Recovery Rate

The most common metric used in analyzing the success of animal tracking studies is the data recovery rate (total pings released/total pings recovered).

1.3.4 delta

Potential for data fusion

1.3.5 Scale of Experiments

1.3.6 Oversights

1.4 Requirements

1.4.1 Scope of Tool

1.4.2 Supported Workflows

1.4.3 Bathymetric File Support

1.4.4 Bathymetric Shadowing

1.4.5 Modeling Animal Movement and Habitat

1.4.6 Ornstein-Uhlenbeck

This is a paragraph about OU.

1.4.7 Random Walk

1.4.8 Evaluation of Sensor Emplacements

1.4.9 Selection of Optimal Emplacements

Here is a picture in figure 1.1.

Figure 1.1: An example of included Encapsulated PostScript (EPS).

Using the package we get the much nicer `<http://www.hotwired.com/webmonkey/98/16/index2a.html>` which LaTeX can handle just fine. Even better, the parameter to `\url` can have spaces inserted anywhere so you can make the LaTeX source lines in your text editor wrap nicely.

A few notes. It is recommended that you enclose your URLs in “<>” to ensure that any punctuation around the URL won’t be confused as part of the URL. You can use URLs in your bibliography too (see the `uhtest.bib` file for an example). Finally, if you need to use a tilde in your URL then things are a little trickier. One way to do it is like this: `<http://www.dartmouth.edu/~jonh/ff-cache/1.html>`. The `\url` style uses math mode internally, so we break the URL into two pieces, and stick a tilde from math mode inbetween the two parts.

CHAPTER 2
RELATED WORK

2.1 Yuan et al - Fast Sensor Placement Algorithms for Fusion-based Target Detection

Using data fusion for enhanced range and accuracy Constrained Simulated Annealing and Optimal Placement

2.2 Poduri et al Constrained Coverage for Mobile Sensor Networks Constrained Coverage (K-Neighbor Networks vs Maximum Coverage)

Density of Deployment Influencing global network properties via local restrictions Force dispersion algorithm

2.3 Pedersen and Weng - Estimating Individual Animal Movement from Observation Networks

Movement models Observation models Network Sparsity Home Range Investigation Assumptions when simulating fish movement in state-space models Fish speed and sensor area Observable space and total study area ?Environmental factors affecting fish behavior?

2.4 Howard et al - Mobile Sensor Network Deployment using Potential Fields Potential Field Algorithm

Static Equilibrium: Optimal placement vs Run time Runtime and Results

2.5 Akbarzadeh et al - Probabilistic Sensing Model for Sensor Placement Optimization Based Signal Simulation and Attenuation (Omni Directional Sensors)

Line of Sight modeling Weighted Coverage L-BFGS, Simulated Annealing, and Covariance Matrix algorithms Here is where you discuss the related work. Use BibTex to reference related work.

CHAPTER 3
DESIGN

3.1 Animal Modeling

Animals exhibit many different movement models and habitat preferences (both of which can vary in three-dimensional space). This greatly affects their distribution and thus the network configuration that should be deployed to capture their movement. Our program models account for both the habitat and movement preferences of the target species by allowing for various optional parameters and functions.

3.1.1 Animal Movement Models

To simulate animal movement across a two dimensional x/y space (as one would expect to see on a map), we provide two basic probabilistic movement models: Random Walk, and Ornstein-Uhlenbeck(OU).

3.1.1.0.1 Random Walk Model The Random Walk model assumes that animals move randomly through the environment. As a result, over the entire study period, each valid grid cell (as defined by vertical habitat range) will see roughly the same amount of animal traffic. The result is that every valid cell in the grid will have the same chance of capturing an animal's sonic tag. We assume that animals will be willing to very briefly (in probabilistically negligible time frames) pass through invalid cells to get to valid cells. This means that disjoint sections of habitat are still capable of seeing animal movement.

3.1.1.0.2 Ornstein-Uhlenbeck Model The Ornstein-Uhlenbeck(OU) model assumes that over time, animals will prefer to gather near certain points of interest. This concept models an animal's desire to seek out and remain near a physically significant structure, a region of high food availability, breeding grounds, shelter, etc. Users must provide the x and y coordinates for this point (as grid indicies), the strength of attraction in the separate x and y directions, and the correlation between the x and y attraction as parameters to the program. http://en.wikipedia.org/wiki/Ornstein

3.1.2 Simulated Animal Depth Preference

Some animals exhibit the preference to reside within a specific section of the water column; for example, prey animals may prefer hiding in reef heads at the bottom of the water column, while predators will prefer to hover several meters off the bottom. This preference can be incorporated into the behavioral model by specifying mean (Preferred Depth) and standard deviation(SD of

Preferred Depth) values. These values are given as a measure of the distance (in meters) from the bottom. For example, specifying a depth of '0' for "Preferred Depth" indicates that the animal prefers to live on the sea floor, while a value of '5' indicates that the animal prefers to live 5m off the sea floor. Allowing a standard deviation value allows for the modeling of animals that tend to be sedentary within the water column (a small deviation), and those that migrate through the water column (a large deviation).

3.1.3 Restricted Vertical Habitat Range

Some animals will live only in a specific depth range. For example, a deep sea fish may live only in depths of 300-400 meters. To incorporate this into the behavioral model, users can specify a minimum and maximum vertical habitat range for their animal. If this option is used, the program will only simulate animals in cells whose depths are between the minimum and maximum depths.

3.2 Sensor Projection

Normally users have a set number of sensors to place in the water. However, the question of How much better could my results be if I had had just a few more sensors? often arises. The program allows for the projection of additional sensor placements, and graphs how much more data collection would have been possible.

3.3 Network Model Ingestion

3.3.1 Customizable Network Models

The program supports three distinct ways to define sensors in a network: user specification, program-placed sensors, and projected sensors. User placed sensors represent sensors that already exist, and are being integrated into a new network. Program placed sensors are sensors that are optimally placed by the program, and take into account any user placed sensors. Projected sensors are Add new sensors (with optimal placement) to an already existing network Analyze the data recovery rate for a sensor network Create an optimal sensor network

3.4 Goodness Algorithms

3.4.1 Selectable Goodness Algorithms (Bias)

The Goodness algorithm is the driving force behind the selection of sensor placements. While users are able to write their own Goodness algorithms, three basic algorithms are provided:

3.4.1.0.3 Animal Only (Option 1) This option prefers to place sensors in areas of high animal activity, completely oblivious to the surrounding topography.

3.4.1.0.4 Topography Only (Option 2) This option places sensors in areas that have the best visibility of the surrounding area. This is useful for experiments where animal habitat is unknown or to be determined.

3.4.1.0.5 Visible Fish (Option 3) This option chooses sensor locations that have the best view of areas of high animal activity. Both animal presence and visibility due to topography are considered.

CHAPTER 4
RESULTS

Here is where you discuss the results from your evaluation.

CHAPTER 5
CONCLUSIONS

Here is where you discuss your conclusions and future directions.

APPENDIX A
SOME ANCILLARY STUFF

Ancillary material should be put in appendices, which appear before the bibliography.

APPENDIX B
MORE ANCILLARY STUFF

Subsequent chapters are labeled with letters of the alphabet.

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