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/Sateallite 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

Construction [Diagram of rigging] SAONs are composed of stationary rigs that are responsible for maintaining the chosen location for a sensor. Because animal 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. 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. 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 can cost up to $4000 each).

Deployment

Recovery

1.2 The Cost of Data

Larger sample sizes and study areas (since a greater number of sensors and tags can be purchased).

Cost of Alternative Technologies SAONs are relatively cheap, with acoustic sensors costing approximately $4000 (including moorings and acoustic releases), and acoustic tags costing approximately $350 each. Moorings for acoustic receivers can be significantly more expensive, with acoustic releases costing nearly three times more. However, these costs are still significantly more affordable than GPS-based tags and collars, which cost upwards of $6000 each. Additionally, recurring service fees and per-transmission charges may apply. A seemingly cheaper alternative is the VHS radio collar, which costs about $300 each, but requires active fieldwork to obtain each data point. The cost of paying field researcher to track these animals will significantly outweigh any initial cost savings.

Table 1.1: Cost Summary of Alternative Technologies

Technology	Tag/Collar	Sensor	Maintenance Cost
VHF Radio Collar/Tag	$300	$???	Salary of field researcher
Satellite Tag	$2000-$4000	$0	Service fees ($1000-$2000 per tag)
Acoustic Network	$300	$1500	$0

Maintenance 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). However, it is necessary to retrieve the acoustic sensors at the end of the study in order to recover data. Finally, SAONs allow for passive animal monitoring, removing the potential disruption of natural behavior caused by active tracking (e.g. boat noise/shadow scaring animals).

[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

1.2.1 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

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).

delta Potential for data fusion

1.3.3 Scale of Experiments

1.3.4 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

Ornstein-Uhlenbeck This is a paragraph about OU.

Random Walk

1.4.6 Evaluation of Sensor Emplacements

1.4.7 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).

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.

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:

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

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.

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.