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ABSTRACT

The ability to accurately estimate signal strength can improve collaborative navigation algorithms by creating greater navigational flexibility and system robustness. This extended abstract describes initial results on the building of underwater acoustic communication maps for an entire 2-D surface area from a small number of signal samples collected at discrete points in the area.

We formulate two types of maps - a local communication map (LCM) and global communication map (GCM). The LCM is defined with respect to a fixed destination point. It is built using kriging techniques to estimate the mean and variance of a random field. The GCM is a compendium of local maps and is built using bayesian inferencing to estimate of a lattice of random fields. The GCM permits a vehicle to estimate communication effectiveness to another location within the bounded region. We present an example LCM and GCM derived from acoustic modem SNR datasets recently collected in Monterey, CA.

1. INTRODUCTION

We are interested in using Multiple AUVs for building a 3-D map in cluttered, dynamic environments. Error bound analysis on collaborative navigation algorithms assume full network connectivity over a fixed time frame. A better understanding of the undersea communication channel may increase this limited time frame which would result in (1) a more robust and effective system, (2) increased navigational flexibility and (3) improved energy efficiency. We also seek to build accurate maps in a least intrusive and most efficient manner in order to minimize impact to the primary survey mission objective.

2. THE LOCAL COMMUNICATION MAP

For some situations one may be interested in understanding the SNR relative to a fixed position. An example might be determining how to optimally deploy a number of anchored acoustic modems which serve as the basis for a Undersea Acoustic Network. The signal relative to a single fixed ground node is an example of a local communication map.

2.1 LCM Definition

The LCM is a topological surface within a bounded survey space. There exists a unique point that represents the fixed communication node's position. This is called the destination. Relative to this point we seek SNR mean and variance estimates for a discrete number of points within a defined maximum distance from the destination.

2.2 Kriging

The bounded survey space is represented as a random field. There are several techniques available for the estimation of the random field. We use kriging (more specifically ordinary kriging) techniques for the LCM to produce a mean prediction and variance estimate of the SNR values. This is due to the fact that *a priori* SNR measurements in a cluttered environment produce non-uniform or anisotropic SNR degradation over increasing distance.

Careful partitioning of SNR measurements to determine spatial relationships may be, at times, very difficult and in those circumstances ordinary kriging maybe the best alternative since unlike bayesian techniques there is no estimate necessary of the covariance function parameters as it is obtained explicitly from the semi-variogram. There are four steps associated with kriging: data transformation, variogram analysis, solving a linear system of equations, calculation the mean and variance.

2.3 LCM Results

The acoustic modem datasets used to build the LCMs were collected in Monterey, CA in August 2011. The underwater acoustic modem used was the Woods Hole Oceanographic Institution (WHOI) μ-Modem. The system was configured at a nominal 27kHz with a set baud rate of 19.2 Kbps.

There were two modems providing single-way communication estimates. An RF-Acoustic gateway buoy was positioned successively at five fixed positions. This was the destination of the modem transmissions. A second mobile μ-modem was deployed from a small support craft maneuvering around the harbor. This was the source of the transmissions. In total there were 5908 acoustic modem SNR measurements. Figure 1 shows the results of a single data set. Notice that south of the D1 destination the variance is higher reflecting the lack of measurements in that region.

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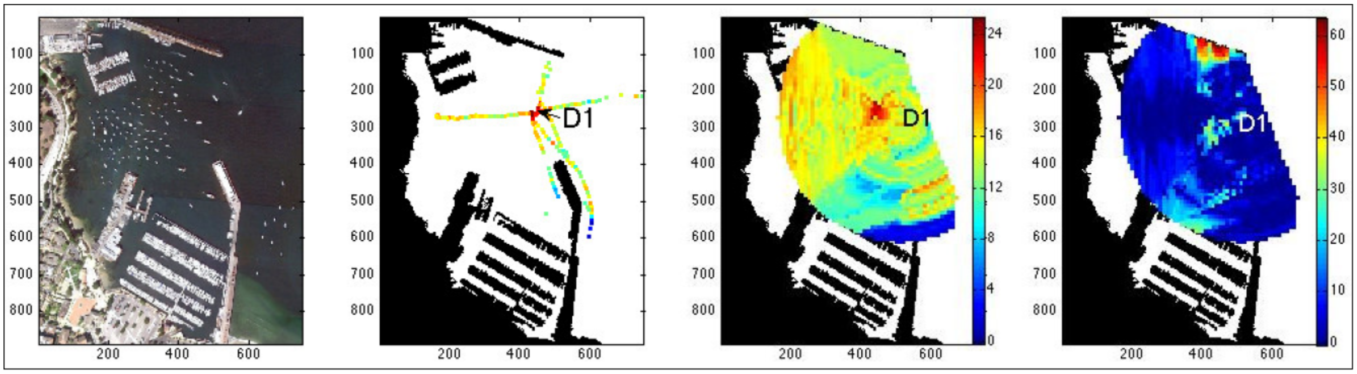

Figure 1: *Left to right. (a). Monterey Harbor, Monterey, CA, (b). SNR measurements with the fixed destination located at D1, (c). The kriging mean estimate, (d). The kriging variance estimate.*

3. THE GLOBAL COMMUNICATION MAP

There are limitations to the LCM. It requires a priori measurements and creates a map of limited utility since it permits SNR estimates relative to a single position. The Global Communication Map (GCM) is meant to address these shortcomings for an incremental, collaborative implementation. It is a representation of the communication landscape such that any AUV in the environment can determine a position to improve the probability of successfully communicating to another AUV. This could also be used to determine where SNR measurements are necessary to gain better map accuracy and resolution.

3.1 GCM Definition

Consistent with the LCM, we define the GCM such that there exists a bounded survey space where we partition it into a lattice and from the center of each grid cell we seek to predict the mean and variance of a random field. Each cell in the lattice has (1) a scalar estimate of the overall ability to communicate omni-directionally (2) a discrete number of vectors which estimate the ability to directionally communicate over increasing distances within a defined bearing window. (3) a scalar estimate of uncertainty associated with the random field. (4) Variance estimates of the SNR vectors. The scalar estimates are calculated as the integrals of the random field over a maximum range.

3.2 Bayesian Inferencing

With the LCM, kriging doesn't take into consideration the uncertainty associated with the covariance function. For the GCM, we look to explicitly take this into account by introducing a bayesian intrepretation. This is known as bayesian kriging. We are interested in predictive estimate of the marginal posterior pdf ($p(Z(q_0)|Z)$ such that
$p(Z(q_0)|Z) = \int_\theta p(Z|\Theta)p(\Theta|Z)d\Theta$.

The first probability on the right hand side of the equation is obtaining the measurements given covariance parameters Θ. The second term ($p(\Theta|Z)$) is the probability of the parameters given the measurements. This is calculated through estimation of the covariance parameters through restricted maximum likelihood estimation (REML).

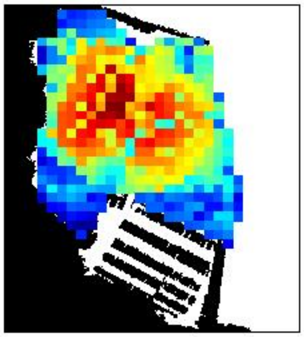

Figure 2: *The GCM produced from the July 2012 dataset. The map resolution is 25 meters square.*

3.3 GCM Results

A second acoustic modem dataset was collected in Monterey Harbor in July 2012. The same destination locations were used for the gateway buoy. This time the surface boat initiated transmission of acoustic messages at positions that more fully covered the outer harbor. There were a total of 5500 SNR measurements. Figure 2 shows the the results of the GCM taking into consideration all data sets. This map reflects the overall ability to communicate from the center of each lattice. Notice the best area to communicate is not obvious since it is near a section of docks and moored boats. One of the benefits of the methodology is that measurements can be used in the estimation of more than one random field; this greatly reduces the sampling requirement to accurately build the GCM.

4. CONCLUSIONS

Initial results demonstrate the ability to create both the local and global communication maps. We feel this is a useful tool for collaborative navigation algorithms since better information with regard to the communication topology can be leveraged to improve inter-communication between vehicles and this in-turn improves system robustness and flexibility. Much work remains to be done. This includes validation of the map accuracy and multi-vehicle strategies to build the maps quickly and incrementally.