Characterization and mitigation of noise for Shallow Water Array Performance (SWAP)

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I. INTRODUCTION

Performance for passive sonar systems operating in shallow water environments has been limited by a number of factors including low target source levels relative to ambient noise, the inherently non-planar nature of acoustic propagation which introduces array mismatch, and the presence of non-stationary surface ships with high signal-to-noise-ratios (SNRs). An open question in the signal processing community is whether large arrays – with the corresponding potential for increased array gain and interference rejection – could significantly increase passive detection ranges. A key component of this question is the ability of adaptive beamforming techniques to effectively null the interference when it is highly non-stationary and large observation times may be necessary to estimate the array covariance matrix.

These issues have been explored previously with targeted data collections (for example, the Santa Barbara Channel Experiment, [1]). However, due to the limited amount of experimental data and the specifics of the array topologies, it has been difficult to provide a general, quantitative assessment of passive performance. Factors such as these have prompted the Office of Naval Research (ONR) to consider the creation of an Acoustic Observatory as a fixed acoustic testbed to support a comprehensive “dB-budget” analysis for passive sonar performance [2]. The array for the ONR Shallow Water Array Performance (SWAP) is scheduled for deployment near the South Florida Testing Facility (SFTF) during summer of 2007, and will be comprised of a single line array of N=500 vector hydrophones. The environment has heavy ship travel and will provide ideal data for performance assessment of adaptive beamformers. In this paper, an analysis of the SWAP array resolution and the impact of this resolution on acoustic source motion is presented. Preliminary statistics of the ship traffic produced from data from a radar installation near the SFTF is presented and discussed.

II. SWAP ARRAY AND SHIPPING ENVIRONMENT

The SWAP array will be modeled as a uniform linear array of length L~900 m and operating at a wavelength λ (the specific case of λ=3.57 is considered throughout this paper). Because of the long length, the array has considerable range focusing ability, and the 3 dB range cells can be derived by a process following [3], which is summarized as follows. First, determine the focus at infinity, which is defined as the closest range to the array at which a cylindrically spreading source will incur no greater than a 3 dB loss with a planar array manifold (no focusing delays). Next, compute the next closest focus range such that its outer 3 dB boundary just overlaps the infinite-range cell. Continue this process for consecutive range cells into the nearfield of the array. If the cells are counted from infinity inwards, the expression for the *p*th range cell is then given by

$$\boldsymbol{dR = \frac{L^2}{8\lambda}\left[p(p+1)\right]} \tag{1}$$

which gives a value of dR=2 km for a source at a range of 10 km from the array. A similar process can be used to determine the bearing resolution, which predicts $d\theta=0.2^{o}$ for a broadside beam. These range and bearing dimensions will form cells that partition the search space; a total of 6635 range-bearing cells is required to cover the entire domain. (This figure assumes that the number of range cells vary as a function of bearing to minimize cell count.)

The expressions for range/bearing resolution can be used to calculate the maximum radial and azimuthal velocity such that the target does not transit through a cell boundary during a given observation time T. The plot in the lefthand side of Fig.1 shows the maximum azimuthal velocity for a broadside source at three different ranges (see line legend) using the full SWAP aperture and 1-sec. snapshots. The value of T is chosen to provide either 2N snapshots (red lines) or 0.25N snapshots (black lines). For the

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later case, note that there are insufficient snapshots to estimate the full covariance array, and a reduced rank architecture would need to be employed. It is expected that for such a large array reduced rank or sub-array architectures will be necessary.

From the figure, it is clear that the high resolution of the SWAP array imposes a severe constraint on allowable source motion. For a source at 6 km from the array, the azimuthal velocity must be less than 5 cm/s to provide full rank snapshot support. Even for a source further out in range (25 km) and with a reduced number of snapshots (0.25N) the velocity bound is 0.5 m/s, which is considerably slower than most surface ship traffic. Sources that transit through cells during the observation time will appear as separate sources. In particular, strong interferers have the potential to be spread across the eigenvector spectrum, thus requiring multiple degrees of freedom for adaptive cancellation. Targets that transit through multiple cells will suffer reduced target power in any given cell relative to a stationary source.

To determine spatial and temporal distributions of ships in the SWAP environment, radar data provided by the SFTF for a four-day period in early April was processed and analyzed. As an example, data for all ships within a 30-km region of the array is shown in the righthand plot of Fig.1 as a function of local time (EDT). From the plot, it can be seen that the number of ships varies diurnally and with tide cycles, with a mean of approximately eight ships in the vicinity of the array at any given period. This distribution can be used to predict the acoustic interference across the SWAP array as a function of the processing parameters (snapshot length, observation time, aperture size, etc.)

III. CONCLUSIONS

This paper presents some preliminary analysis for the ONR SWAP effort in the form of motion bounds relative to the array resolution and initial examination of ship traffic in the SWAP vicinity. Ongoing and future work will compare these predictions with SWAP data as it becomes available, and develop motion-tolerant adaptive beamforming architectures.

REFERENCES

[1] L.M. Zurk, N. Lee, J. Ward, "Source motion mitigation for adaptive matched field processing," *J. Acoust. Soc. Am.*, 113, 2003, pp. 2719-2731.

[2] N.L. Owsley, "Site-specific passive sonar performance prediction," *Asilomar Conf. on Signals, Systems and Computers*, 1, 2002, pp. 415-420.

[3] Theo Kooij, "Resolution Cell Center in Range and Azimuth," (unpublished).

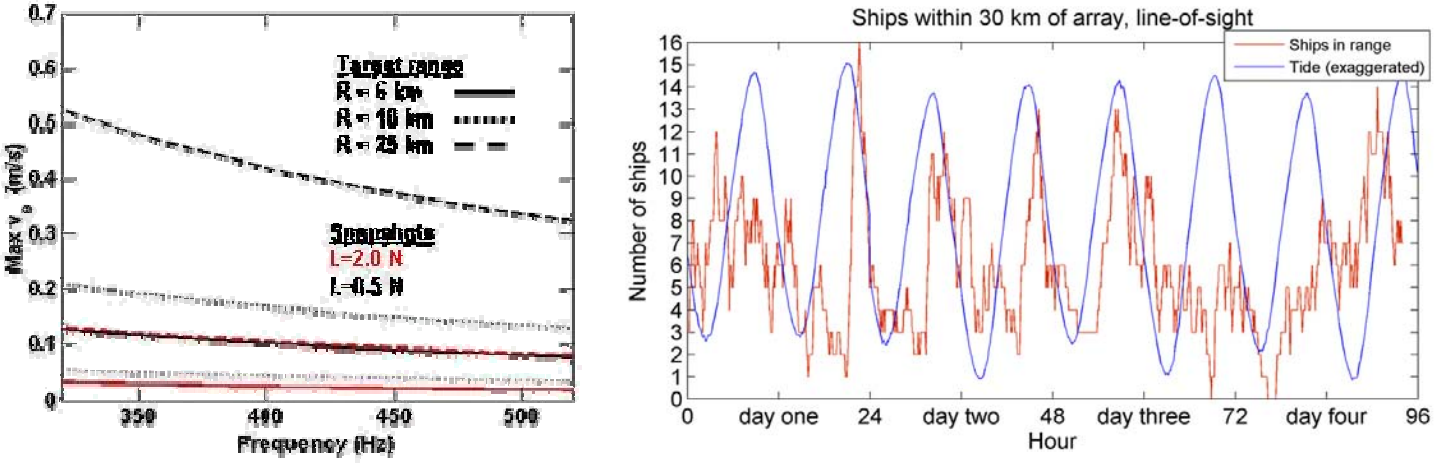

Fig. 1. Left: maximum azimuthal velocity for a broadside acoustic source to remain within a SWAP resolution cell. Right: number of ships in SWAP vicinity produced from radar tracks and AIS information from SFTF.