Measuring the spatial characteristics of the ambient noise field from an autonomous underwater vehicle

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For autonomous underwater vehicles (AUVs), the primary method of sensing the local environment is through acoustics. The local noise field contains a wealth of information the AUV uses - from target tracking to communication to general understanding of the environment. An assessment of the spatial composition of the ambient noise field can provide details about the physical environment as well as information for the AUV to incorporate into its control decisions. The challenge is in accurately measuring the directionality of the noise field from a single line array while continuously updating this measure to reflect changes in the environment and additional information as the AUV moves. This analysis presents a method for continuously assessing the spatial characteristics of an ocean ambient noise field measured by an AUV with a towed hydrophone array.
INTRODUCTION

Autonomous underwater vehicles (AUVs) are becoming increasingly used in a variety of underwater applications. Whether for tracking targets, communication, or for some other purposes the AUV is continuously attempting to sort through the local noise. Maintaining a continuously updating measurement of the ambient noise field can greatly help to distinguish between the noises it is listening for (target tracking, communication, etc) and the background noise field. For a towed line array the measurement of the field itself can pose some challenges.

The use of a moving array - such as a line array towed behind a moving AUV - provides distinct advantages for the measurement of the ambient noise field. This paper presents results using an adaptation of the Wagstaff [2, 3, 4] iterative technique to continuously update the assessment of the noise field. This analysis presents results from both experimental data and simulation for measurement of the spatial characteristics of the ambient noise field from an AUV.

ENVIRONMENT & MODEL

The results presented here come from both simulations and analysis of data taken by an AUV with a 32 element towed line array at a testing run in Massachusetts Bay on December 2, 2011. The simulation assumes the same environment as the testing site in Massachusetts Bay. Figure 1 shows the region modeled in the simulation. The box (denoted by the four corners A, B, C, and D) is the 4 km by 4 km safe operations box, within which the AUV maneuvers. For these results, the AUV was instructed to station-keep, meaning it followed a hexagonal path (as shown in the inset of the figure) 30-40 m radius from a specified station. In the simulation, targets - both stationary and moving - were arbitrarily created outside this box.

FIGURE 1: Massachusetts Bay testing area where data was acquired, and used for simulation model. Box (denoted A, B, C, D) shows safe operations region where AUV maneuvered. Inset shows a closeup of the AUV’s tracks when station keeping.

ANALYZING THE NOISE FIELD

Steering the array to various directions [1] is the traditional way of measuring the noise level from various direction. However, this leads to problems with both beam pattern effects and side-to-side ambiguity due to the array shape. The results from this straightforward computation are presented to compare with the estimation of the noise field using a continuously updating iterative technique.

The method used here to estimate the spatial characteristics of the ambient noise field is adapted from Wagstaff [2, 3, 4]. This iterative technique was used to post-process the data to extract an estimation of the ambient noise in 2 or 3 dimensions. Though not the first time this technique has been used to analyze the
noise field from an AUV [5], this analysis uses an adaptation of this iterative technique to run onboard the AUV and produce a continuously updating measure of the ambient noise field.

The AUV’s array uploads the recordings on each element every 2 seconds. Each of these records is split into 10 0.2 second sections and averaged, and then the frequency response is extracted. The desired frequencies (generally 900 Hz, as this is the frequency used for the targets and ambient noise model in the simulation) for 6 minute periods of data are then analyzed using the iterative technique as described in the Wagstaff papers.

Six minutes was chosen as that is slightly longer than the AUV uses to perform at least half of a circuit when station keeping. Given different experimental setups, this period of time can be changed.

**Simulation**

For this simulation, the AUV was set to station keep and a target was set to drive west to east several kilometers north of the AUV. Figure 2 shows the results when the noise field is calculated using just plane wave beamforming to look in all directions. The results are dominated by the beampattern due to the line array orientation and it is impossible to make out the target. The left plot shows the raw measurement of the noise level $NL$ for a short simulation run: the horizontal axis is the angle $\theta$ the array is beamed ($0^\circ$ is due north), and the vertical axis is the time in seconds of the simulation run. The color axis is in dB. The right plot shows the heading of the AUV in degrees (horizontal axis) over the time of the simulation (vertical axis).

![Figure 2](image)

**FIGURE 2:** Measured noise level from AUV. The left plot shows the raw measurement of the noise level $NL$ for a short simulation run: the horizontal axis is the angle $\theta$ the array is beamed ($0^\circ$ is due north), and the vertical axis is the time in seconds of the simulation run. The color axis is in dB. The right plot shows the heading of the AUV in degrees (horizontal axis) over the time of the simulation (vertical axis).

This same simulation was then processed using the continuously updating iterative technique described above.
**Figure 3:** Noise field measured continuously using 6 minute compilations of the simulation. The horizontal axis is the angle of the noise field, the vertical axis is the time of the simulation run. The color axis is in dB and reflects the relative noise level difference between the isotropic ambient noise measured and the target.
Figure 3 shows the noise field measured continuously using 6 minute compilations of the simulation. The horizontal axis is the angle of the noise field, the vertical axis is the time of the simulation run. The color axis is in dB and reflects the relative noise level difference between the isotropic ambient noise measured and the target. The target was set north of the AUV (in the generally 0° direction) moving from west to east (i.e. increasing angles).

Data

This data was taken in early December 2011 in the Massachusetts Bay. This analysis uses approximately 80 minutes of data when the AUV was primarily station-keeping. During parts of this time a 900 Hz target was active and moving. This analysis was done over multiple frequencies, and is shown with two frequencies to see both the 900 Hz target and response from environment noise (i.e. ships) at 400 Hz.

The measured noise level for each 2 second update of by the AUV is shown in Fig. 4 for both 400 Hz (left plot) and 900 Hz (middle plot), as well as the measured AUV headings (right plot). For all three plots the horizontal axis is the direction the array steered in (0° is due north), the vertical axis is the time (in seconds) for this particular run of the AUV. For the measured noise level plots (left and middle) the color axis is shown in dB and is the same for both. From the middle plot we can clearly see when the target was active (i.e. in the first 1800 seconds, and from approximately 3000-4600 seconds) but due to the moving AUV and the effect of array response (beam pattern) it is impossible to directly extract the moving target.

Figure 5 shows the continuously updated measure of the noise field. Again the analysis was done at multiple frequencies and shown for both 400 Hz and 900 Hz. The horizontal axes give the direction of the noise or heading (0° is due north); vertical axes gives the time in seconds for this run of the AUV. The left and middle plots show the measured noise field at 400 and 900 Hz respectively, and the color axes are the noise levels calculated in dB. The right plot shows the heading of the AUV for the same times.

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These results show both the motion of the target (in the 900 Hz analysis, shown in the middle plot), as well as movement of some noise sources in the local environment - likely of ships of the experiment - shown on the 400 Hz analysis on the left plot.
**FIGURE 5:** Measured noise field for approximately 80 minutes of experimental data when the AUV was station keeping. Horizontal axes give the direction (0° is due north), vertical axes gives the time in seconds for this run of the AUV. The left and middle plots show the measured noise field at 400 and 900 Hz respectively, and the color axes are the noise levels calculated in dB. The right plot shows the heading of the AUV for the same times.
DISCUSSION

This paper presents a method for assessing the spatial characteristics of an ocean ambient noise field measured by an AUV with a towed hydrophone array. Using both simulation and experimental data, this iterative noise field measurement technique can provide a continuously updating calculation of the local ambient noise field, including accounting for moving targets. Multi-frequency analysis of the experimental data allows for seeing noise field across a broad frequency band which in turn provides greater understanding of the local field.

ACKNOWLEDGMENTS

Many thanks to everyone at the MIT Laboratory for Marine Sensing Systems for all their help with the simulator and acquiring the data presented here.

REFERENCES


