RANGE DEPENDENT MATCHED-FIELD SOURCE LOCALIZATION AND TRACKING IN SHALLOW WATER ON A CONTINENTAL SLOPE

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INTRODUCTION

The postwar advances in ocean acoustics has been significant. The ever-growing silent and quiet modern diesel-electric submarine has generated enormous amounts of research and developments in an effort to counter a submarine's greatest strength ... it's covert nature. In passive acoustics, advanced beam-forming techniques have been highlighted as a viable solution to provide useful operational capability against the perpetual threat of a submarine.

The threat has been complicated even further as the tactical setting has migrated to a littoral environment far more difficult than for open ocean regions. The time and distance scales of near shore environmental phenomena are shorter and because the sea is acoustically shallow it creates a more complex acoustic environment.

The aim of this paper is to provide insight on one aspect of adaptive beam-forming, matched field processing, that exploits all environmental conditions to localize a moving underwater target along a coastal region.

MODELLING

Acoustic data were collected using a multi-element vertical line array during the Pacific Shelf experiment off the west coast of Vancouver Island. A 16-element array was suspended from a surface float in water depths of 380-400 m, with the top hydrophone at a depth of 90 m and the elements equi-spaced at 15 m intervals. A CW sound source was towed along specific tracks, projecting three tones in the 45 - 72 Hz band. In this paper, data obtained for a downslope radial track out to a range of 5.5 km and along an arc at the same range are processed to localize the source in range, depth and bearing. The GPS track is shown by the dotted curve in Figure x.

The source location was estimated using a Bartlett matched-field (MF) processor, which acts as a simple correlator between the measured and modelled fields. Its output value is given by [1]:

$$P_B(\hat{\mathbf{m}},r,z,\theta,t) = \hat{p}_n^*(\hat{\mathbf{m}},r,z,\theta,t)\ \underline{C}_t\ \hat{p}_n(\hat{\mathbf{m}},r,z,\theta,t)$$

- $\hat{p}_n(\hat{\mathbf{m}},r,z,\theta,t)$ is the modelled field for a variable environment model $(\hat{\mathbf{m}})$ and source position r, z, θ in time t.
- $\underline{C}_t$ is cross-spectral matrix for the measured field at time t.

An adiabatic normal mode expression that satisfies reciprocity was used in order to compute the replica field $\hat{p}$ [2]:

$$\hat{p}(\hat{\mathbf{m}},r,z,\theta) \cong \alpha \sum_{m=1}^{M(r,\theta)} \Psi_m(\hat{\mathbf{m}},r=0,z_s,\theta_i)\,\Psi_m(\hat{\mathbf{m}},r,z,\theta)\ * \frac{e^{i\int_0^r k_{rm}(\hat{\mathbf{m}},r',\theta)\,dr'}}{\sqrt{k_{rm}(\hat{\mathbf{m}},r,\theta)\,k_{rm}(\hat{\mathbf{m}},r_s,\theta)\int_0^r \frac{dr'}{k_{rm}(\hat{\mathbf{m}},r',\theta)}}}$$

- where θ is the azimuth bearing direction and θ_i is the first bearing in an arc of investigation.
- Ψ_m is the mode function of the mth mode and k_{rm} is the associated wave number for a range-dependent environment which is varying slowly in r and range-independent in the segmented, r'.
- α is a constant.

For rapid repetitive computations, the bathymetry, mode functions and wave numbers are pre-computed for a grid of values of the water depth and source depth and stored in "look-up" tables for fast reference [3].

MATCHED FIELD SOURCE LOCALIZATION AND TRACKING

The MF localization results for selected portions of the track are listed in Table 1. Time 1815 was at the start of the tow near the array; the track proceeded to a maximum radial range at 1840 and completed the turn along the arc by about 1842; at 1920 the source had returned upslope to water depths roughly equal to those at the array.

The greatest bearing resolution is expected for the cross slope propagation paths, from about 1910 to 1930. The MF localization in range and bearing are shown in Figure 1 by the crosses (+), based on 38 second samples at one minute intervals. The range-bearing discrimination is very good for the later times along the arc where the change in the field (or transmission loss) per unit angle is greatest. The performance was not as good near the end of the radial; this result may also indicate mismatch in the geo-acoustic model at the deeper portion of the slope.

The source depths estimated by MFP are also plotted in Figure 1; the heavy curve is a polynomial fit. The measured depths, except near the turn, were about 40 to 45 m.

Time	True Range	True Bearing	P_B	MFP Range	MFP Depth	MFP Bearing
1815	1470	288	0.821	1900	69	283
1840	5679	255	0.529	5375	45	253
1855	5459	281	0.716	5850	55	279
1920	5226	327	0.784	5425	39	328
1929	5196	346	0.886	5000	35	346

Table 1: Target Tracking Summary (selected values)

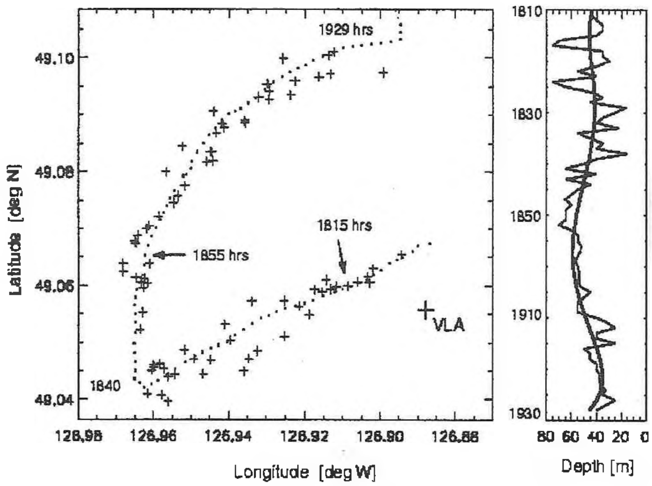

Figure 2: Geographic target tracking (1810 hrs - 1930 hrs)

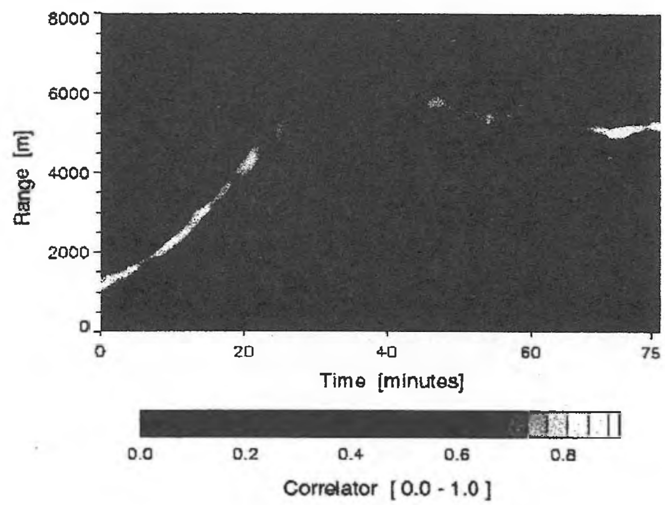

Figure 2: Best Bartlett plotted as Range vs. Time

The results presented at Figure 1 demonstrate remarkably good tracking performance using conventional MFP with a vertical line array over a sloping bottom. The range dependence introduced by the sloping bottom breaks the cylindrical symmetry of the acoustic field, and provides the means for bearing resolution with the VLA.

The tracking results were then further elaborated, Figure 2, showing the best Bartlett correlation plotted as an ambiguity surface of the source range versus time along a known bearing. It demonstrates a dramatic representation of the target's movements.

CONCLUSION

The littoral environment with a complete knowledge and understanding of the bathymetry, geo-acoustic and water column properties provide a powerful tool that exploit all the available parameters to produce accurate and reliable target localization. Specifically related to this experiment, the tracking results sufficiently show the unique tracking over the azimuthally dependent environment. The matched-field localization provided evidence that the breaking symmetry of the continental slope allows the means for bearing resolution with a vertical line array.

Although, not all littoral regions will have a sloping bottom with a gradient sufficient to produce distinct MF bearings, however, the complex nature of shallow water or coastal regions can be exploited to effectively provide enough data to process discriminate tracking along a time-scale.

This paper is meant to demonstrate that the progression of matched field processing and tracking in a complex, spatially varying environment, serves to better refine the tracking capabilities of passive acoustic localization. from conventional beam-forming methods. This is by no means a panacea. The pursuit to counter hostile underwater threats only emphasizes the need to continue these advances.

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