Proceedings of the Eighth European Conference on Underwater Acoustics, 8th ECUA
Edited by S. M. Jesus and O. C. Rodríguez
Carvoeiro, Portugal
12-15 June, 2006

PERFORMANCE COMPARISON OF ARRAYS OF DIRECTIONAL VERSUS OMNIDIRECTIONAL SENSORS USING BASE '04 DATA

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Abstract: *Traditional passive-sonar towed-array receivers use a linear set of omnidirectional hydrophones. Beamforming a linear array achieves a reduction in effective background noise and allows the localization of targets within a directional beam. By replacing the omnidirectional hydrophone sensors with "left-right" discerning directional sensors, beamforming can be undertaken with sets of "left" and "right"discerning beams. For an active sonar, this means that targets can be localized without the classic left-right ambiguity. Furthermore, this left-right bearing discrimination has the benefit of reducing reverberation levels. The improvement in sonar performance in a homogenous reverberation environment is significant. In an inhomogeneous reverberation environment where capability may be severely limited by clutter of geological origin, it is even more dramatic. Data collected with the DRDC Atlantic DASM (Directional Acoustic Sensor Module) receive array during the BASE 04 (Broadband Active Sonar Enhancement 2004) sea trial serves to demonstrate the improvement in performance that is achievable with such an array.*

1. INTRODUCTION

The use of a towed linear array of receivers for low-frequency active sonar has many advantages. The linear geometry allows the array to have a significant aperture and therefore relatively narrow receive beams may be formed. However, a linear array of omnidirectional sensors has an important limitation. Its measurements only result in an estimate of the conical arrival angle to the array axis; there is no inherent ability to distinguish between left and right sides. This limitation may be overcome by replacing individual omnidirectional hydrophones with directional sensors.

An approach is to combine an omnidirectional hydrophone with a horizontal dipole sensor. The horizontal dipole can be constructed from two orthogonal transverse dipoles and a roll resolver. This is the approach used in the Directional Acoustic Sensor Module (DASM) [1,2]. Other approaches, not described in this paper, use multiple (three or four) omnidirectional hydrophones in close proximity [3].

The remainder of this paper will give a description of the research system, and an experiment to compare the performance of an omni-hydrophone array with the performance of the DASM array. A previous paper [4] considered the reduction in reverberation attained through using a DASM array over an array of omnidirectional hydrophones. The focus of this paper is the improvement in target discrimination through using a DASM array over an array of omnidirectional hydrophones. Though this paper focuses on the results obtained from the specific DRDC Atlantic system, the results are easily generalized to other arrays of directional sensors [3].

2. EXPERIMENTAL APPARATUS

Figure 1 shows the tow configuration employed to collect the data. The DASM array consisted of 94 directional sensors with 0.5 m spacing and digital telemetry. The signals from these 188 digital channels (94 omni and 94 dipole) were processed for display to an acoustics operator. One hundred and twenty eight beams were formed with equal spacing in the cosine domain assuming a sound speed of 1500 m/s. The source consisted of a vertical array of Free Flooding Ring projectors [1,5,6].

Figure 2 shows the Combined Omni-Resolved Dipole Sensor (CORDS) [1,2,7,8,9] as used in the DASM array. The sensor consists of an two summed omnidirectional hydrophones (h/p in Figure 2) and a roll-resolved Horizontal-Dipole particle accelerometer (HD). Adding or subtracting the weighted and integrated HD from the omnidirectional pressure sensors can form left and right "looking" cardioids. In practice, the dipole is weighted before the addition, resulting in a limaçon, rather than a cardioid.

The HD sensor consists of two cantilevered beams with pairs of orthogonal accelerometers on the outside of the beams (See Figure 2). The figure shows a cross section, so that only one pair is shown on each beam, the other ceramic is orthogonal to the cross section. The two cantilevered beams form a cross-dipole sensor. The roll resolver consists of a mercury-filled tube with sine and cosine shaped electrodes (not shown in the figure). The version of the sensor shown has the roll resolver inside the cantilevered beams. Older versions had the roll resolver as a completely separate sensor. Newer units have replaced the mercury roll resolver with solid-state units.

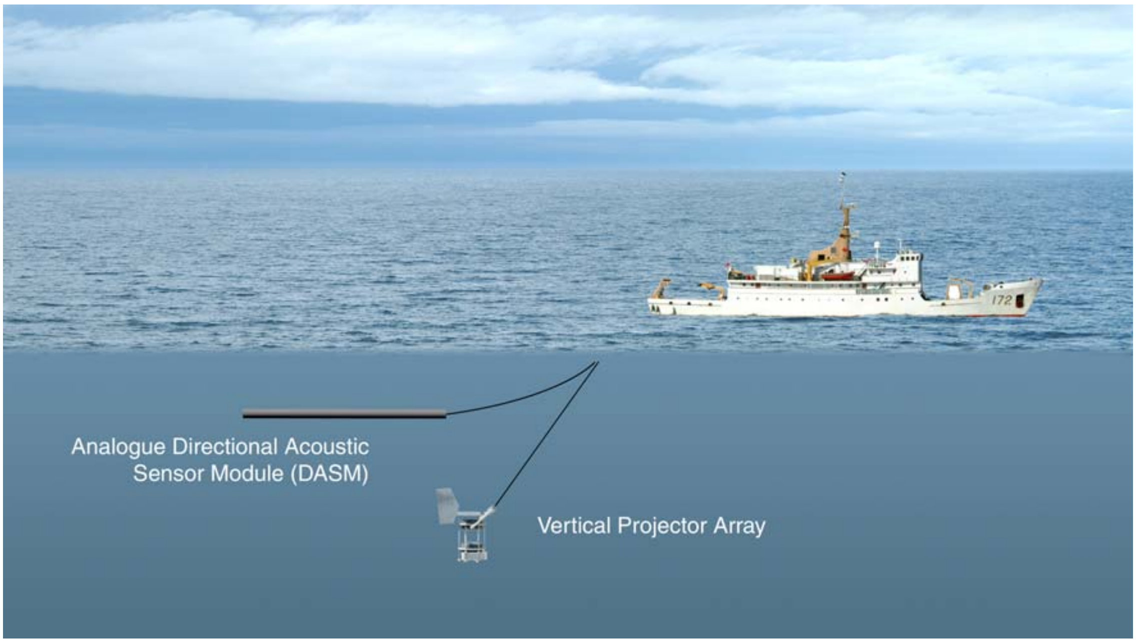

Fig.1 Cartoon showing tow ship, DASM towed receive array and vertical projector array.

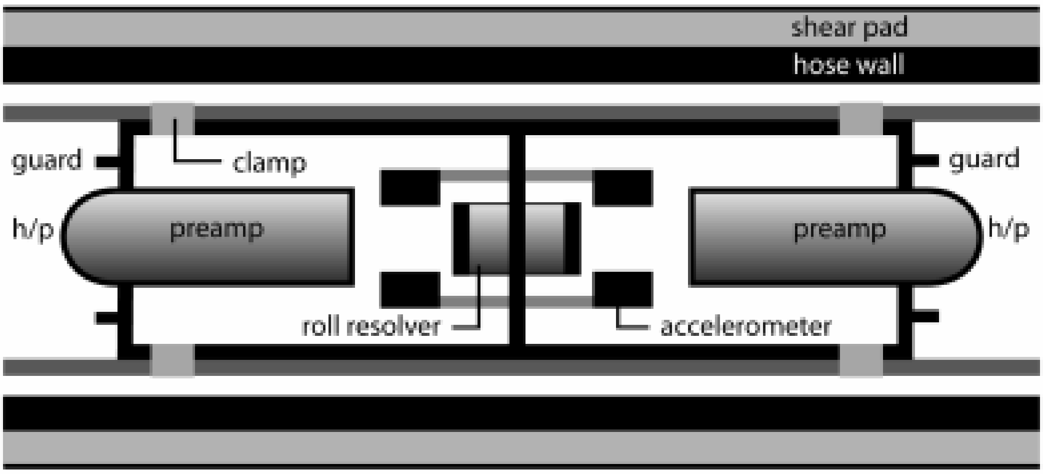

Fig.2 Combined Omni-Roll-resolved Dipole Sensor

3. SIGNAL PROCESSING

The first processing stage requires integration of the dipole sensor to estimate particle velocity from the acceleration. The integration processing combines a three step process. After converting from fixed point to floating point, the HD signal calibration is added. The signal is then integrated and finally, a single-pole high-pass Infinite Impulse Response (IIR) filter is applied to remove any DC component in the signal. Over time, a small DC component would cause the integrated value to continue to grow until the output causes an overflow.

In order to produce a set of beam time series, the omnidirectional and integrated dipole channels are then combined using a time-delay beamformer to form 128 beams covering a full 360° sector. Conceptually, the time-delay hybrid beamformer can be divided in two steps: (*i*) a limaçon beamformer and (*ii*) a conventional linear beamformer. However, in practice, the limaçon beamforming and linear beamforming are performed simultaneously by combining limaçon and linear beamforming coefficients in a single set of weighting factors and time delays.

The limaçon part of the hybrid beamformer can be summarized as follows: If $x(t)$ and $y(t)$ are the pressure sensor and the integrated HD time series respectively, then $s(t) = [\alpha + (1-\alpha)\cos^2(\phi_0)]\, x(t) + (1-\alpha)\sin(\phi_0) y(t)$ represents a limaçon time series, where ϕ_0 is the steering direction (from forward endfire). Using limaçon beamforming, the CORDS sensor has the maximum response in the direction of interest. The term α is used to reference the peak response of the combined sensor to the peak response of an omnidirectional hydrophone. A previous paper [3] considered the restricted case $\alpha = 0.5$, $\phi_0 = \pm 90°$ (cardioid case) for a previous analogue version of DASM. Significant computational savings may be realized using the cardioid approach; however, it yields sub-optimum performance near the endfire directions. Note that by using $\alpha = 1$, only the omnidirectional hydrophones contribute to the resulting beam time series. This property was used to generate the omni beams presented in the next sections.

In this paper, the linear part of the hybrid beamformer is based on a conventional linear beamformer [10]. Note that improved performance may be achieved in some situations through adaptive techniques [11,12]. Subsequent to the hybrid beamformer, its output is matched-filter processed and the matched-filter (replica correlator) output is normalized to an equivalent energy detector response.

4. EXPERIMENT

The data shown in the remaining section were collected on the Malta Plateau on June 1st, 2004, at approximately 12:26UTC. The ship was at 36°18.317'N, 14°43.154'E, travelling on a heading of 018.0° T, with a speed of 2.5 m/s. The depth-sensor logs show the array depth was 66 m.

Figure 3 shows the location of the vessel and the measured match-filtered time series based on a 1.25 s long HFM (Hyperbolic Frequency Modulated) pulse of 50-Hz bandwidth centred at 1125 Hz.

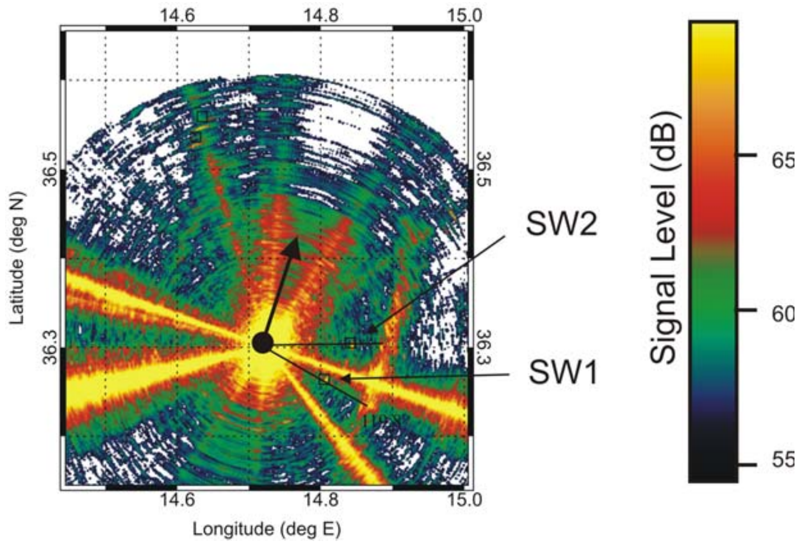

Fig.3 Plan view showing reverberation map, ship heading (arrow) and wrecks (square boxes) of interest.

5. RESULTS - HYBRID BEAMFORMER DIRECTIVITY PERFORMANCE

The directivity performance of the hybrid beamformer is considered by analyzing the beam time series for beams steered towards the targets SW1 and SW2 (wrecks) in Figure 3. SW1 and SW2 are at 10.8° and –18.2° relative to the starboard broadside direction (108°T). Thus, both targets constitute good candidates for testing the hybrid beamformer performance near broadside.

Figure 4 presents the time-averaged signal (using a 0.1s sliding window) of a replica-correlated beam time series pointing at SW1. In the upper part of Figure 4, the thin green line represents the omni beam pointing at SW1 while the thick red line represents the DASM right beam pointing at SW1. In the right-hand part of the figure, the thick blue line represents the DASM left beam pointing toward the ambiguous image of SW1. As expected, the hybrid beamformer does discriminate at broadside; the DASM right beam shows the ridge and the target echo while the DASM left beam does not. The target echo appears on the right beam with a strong left-right discrimination of about 20dB in this particular case. For the same configuration, Figure 5 presents the DASM and omni beams pointing at SW2. It can be seen that for a beam 18.2° away from broadside, the same comments apply as per Figure 4 regarding the hybrid beamformer left-right discrimination.

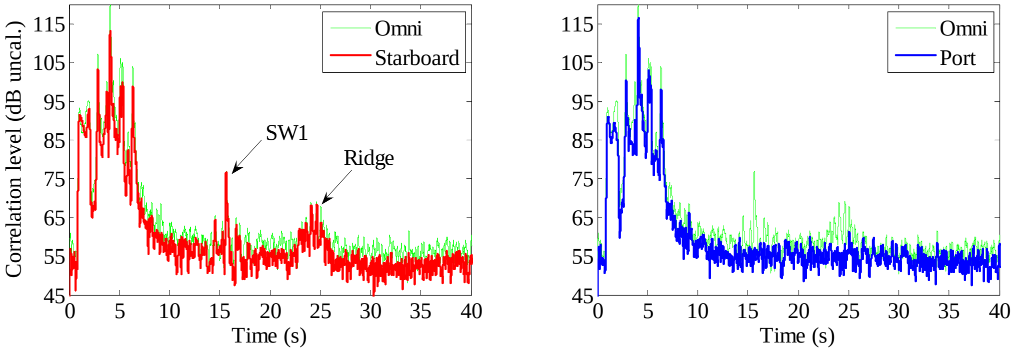

Fig.4 Hybrid beamformer performance 10.8° away from broadside.

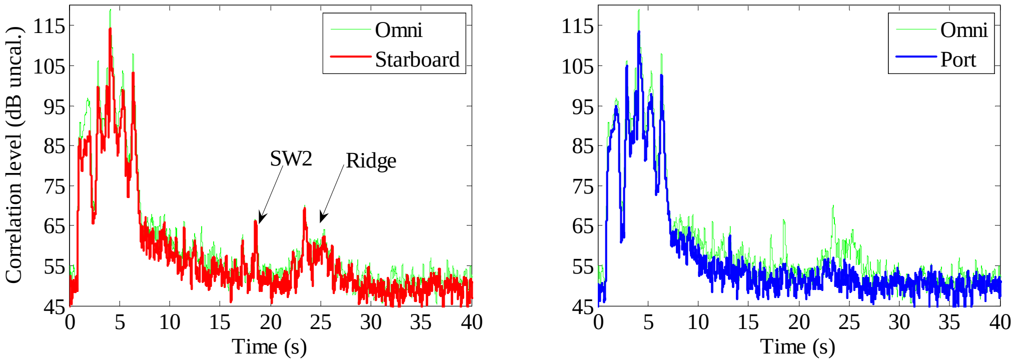

Fig.5 Hybrid beamformer performance 18.2° away from broadside).

Table 1 contains a more quantitative analysis of the beams steered at SW1 and SW2. The hybrid beamformer provides an SNR Gain of 2.12 dB when comparing DASM and omni processing for a beam 10.8° away from broadside. It provides a 1.4 dB SNR gain for a beam 18.2° away from broadside. At broadside, the omni and dipole are added with equal weighting. Assuming omnidirectional and incoherent noise, for a beam steered at broadside, the hybrid beamformer provides a theoretical 3 dB SNR gain when comparing DASM and omnidirectional hydrophone receive array processing. Under this same scenario, the highest left-right discrimination of the beamformer must be observed at broadside since the omni and dipole sensor signals are expected to add coherently on one side while cancelling out for the opposite beam.

TARGET	DASM SIGNAL LEVEL (dB)	DASM NOISE LEVEL (dB)	DASM SNR (dB)	OMNI SIGNAL LEVEL (dB)	OMNI NOISE LEVEL (dB)	OMNI SNR (dB)	SNR GAIN (dB)
SW1	83.81(*)	57.07	26.74	84.12(*)	59.5	24.62	+2.12
SW2	73.55(*)	53.02	20.53	73.75(*)	54.62	19.13	+1.4

Table 1. *SNR gain at broadside*

(*) The signal peak level was measured on non-averaged data (*i.e.* not on data presented in Figures 4 & 5)

6. CONCLUSIONS

This paper has demonstrated the directivity performance of the DRDC Atlantic DASM array using a hybrid (limaçon-linear) beamformer. In comparison with a conventional linear array, the expected SNR gain and left-right discrimination at broadside were both observed using measured echoes from wrecks. The directivity performance of DASM could be further improved using more advanced beamforming techniques [11,12]. The unique DASM technology has already shown its promising potential using classic signal processing techniques. Adaptive beamforming would exploit the full capabilities of this directional sensor.

ACKNOWLEDGEMENTS

This work was made possible by the BASE ’04 Joint Research Project, a collaboration between NATO Undersea Research Centre and Defence Research & Development Canada – Atlantic. The results could not have been achieved without a significant team effort. The authors would like to acknowledge the contributions of Mr. J. Bottomley, Mr. G. Baker, Mr. G. Hemphill, Dr. S. Pecknold, Mr. M. MacKenzie, Mr. K. Rhyno, and Mr. B. Skinner.

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