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ACTIVE DETECTION ENHANCEMENT IN COASTAL AREAS

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Abstract: *The processing chain used for active detection analysis in association with measures of performance that allow real time performance monitoring is presented. Real life examples demonstrating environmental volatility associated with water column temperature variations and background interference changes from ambient noise to reverberation are presented. The effectiveness of broadband pulses against reverberation interference is verified using real data by estimating the average reverberation reduction as a function of bandwidth B to be approximately 8·logB.*

Keywords: *active detection, active processing chain, environmental volatility, reverberation suppression.*

1. INTRODUCTION

The transition of active sonar utilization from blue waters to shallow water coastal areas was accompanied with a technology transition from narrowband to broadband. The main reasons for this change are: a) reverberation suppression, b) improved clutter signature, c) inter-platform and multi-sensor compatibility in multistatics, d) narrowband reaching its theoretical limits, e) the ability to go narrowband from broadband - but not vice versa, and e) the availability of sufficient computer power for fast processing of wide spectrum signals. The strongest motivation for the deployment of broadband active systems is their potential to enhance detection performance in reverberation-limited areas through increased signal bandwidth, i.e. small resolution cell [1,2]. Reverberation reduction as a function of increased bandwidth is demonstrated here in the absence of target echo. Furthermore the performance of active systems in shallow waters is inhibited by environmental volatility related not only to the propagation characteristics of the acoustic channel, but also to different types of background interference. These two issues of channel variability and reverberation suppression are presented through real life examples as obtained during active detection experiments organized and executed under the aegis of the Centre in the Malta Plateau, South of Sicily, Italy [3,4,5].

Section 2 presents the Centre's processing chain and measures of performance to enable performance monitoring and real time feedback. Section 3 demonstrates temperature and background interference variability in shallow water as manifested during active detection sea trials. Section 4 examines the relationship between bandwidth increase and reverberation suppression, and finally Section 5 summarizes conclusions and provides future directions.

2. NURC'S ACTIVE SIGNAL PROCESSING CHAIN AND MEASURES OF PERFORMANCE

Active sonars, contrary to passive, know more about the signal to be detected and therefore the matched filter (MF) that correlates the received signal with a replica of the transmitted signal is the central piece in active detection processing. However, each detection algorithm has additional processing steps to achieve azimuthal directivity, background interfering, post-detection energy integration etc. to improve signal detectability. Fig. 1 illustrates the active processing chain with the corresponding measures of performance used at NATO Undersea Research Centre [3].

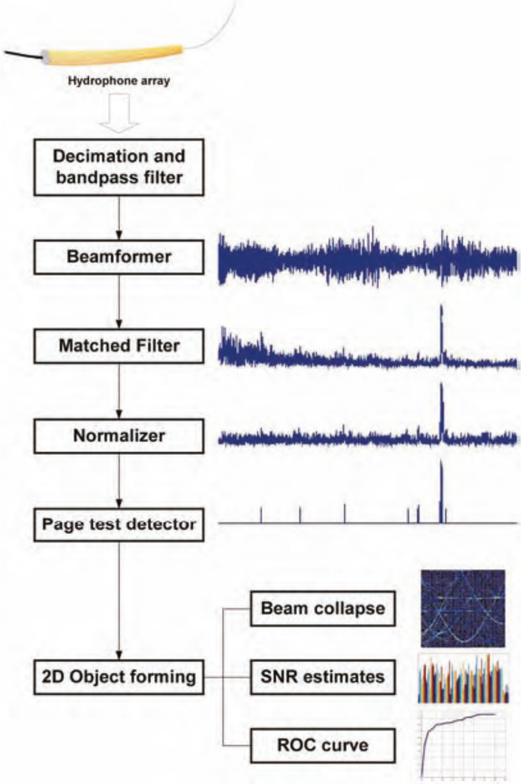

Fig. 1. Active detection processing chain and measures of performance.

The data received on the horizontal array are bandpassed and down sampled (decimation) to speed up processing. Then they go through the beamformer to improve bearing accuracy and detection directivity. Depending of the array type, two beamforming algorithms may be applied: cardioid beamforming that has right/left discrimination capabilities, or standard line array beamforming that has directionality ambiguity. Then the MF is applied to correlate the received signal with replica(s) of the transmitted pulse(s). The output of the MF becomes input to the normalizer whose main function is the removal of the time (or range) dependence of background interference. This allows the application of a single detection threshold for the entire time series, for a given false alarm rate. All normalizers operate on the magnitude squared of the MF output. The Page test that follows is an inspection scheme designed to detect changes in the distribution of a data sequence. When applied to the normalized MF output time series it identifies the beginning and the end of a strong signal in a noisy background. It permits the sequential energy summation of a time-spread echo in an incoherent fashion, therefore it functions as a sub-optimum detector (an optimum detector would incorporate coherently the multipath propagation structure and the target echo characteristics). Afterward a clustering algorithm produces objects characterized by its boundaries in the time-beam space, its peak or mean value and its centre of gravity. From this final detection output three measures of performance are derived: a) beam collapse output: for each ping and range it identifies and plots the maximum output from all or a selection of beams; it is useful as a simple tracker of strong echoes during the run, b) the signal-to-noise ratio (SNR) for target echoes which is the ratio of the maximum signal output to the power of the background interference and is a local measure of detection performance, and c) the Receiver Operating Characteristics (ROC) curve that plots the probability of detection vs. false alarm rates and is a global measure of performance.

3. ENVIRONMENTAL VOLATILITY AND BACKGROUND INTERFERENCE

In active sonar detection it is important to monitor the variability of the acoustic medium in real time. In the examples presented here the observations were obtained during active detection experiments through the sonar processing chain or using external equipment. Fig. 2 shows two cases of temperature variability of the upper 100 m of the water column. The measurements were made using the Instrumented Tow Cable (ITC), courtesy of Naval Undersea Warface Centre (NUWC) [5,6]. The cable contains optical fibers in cable armor divided into 1 m measurement cells to provide 1 m resolution along the cable in real time. Temperature measurements are based on photon energy differences during optical scattering inside the fiber. At the end of the cable there are pressure and temperature sensors for double-ended measurements to reduce calibration errors. The plot on the left shows a continuous temperature profile along an exercise track. In the NW/SE direction an influx of cold-water masses toward the upper layers is identified. The plots on the right show temperature measurements versus depth and time for the same track in two consecutive days. The measurements were made at the same time of day to facilitate comparison. The temperature differences shown are sufficient to alter the propagation characteristics of the same acoustic path within a 24-hour period.

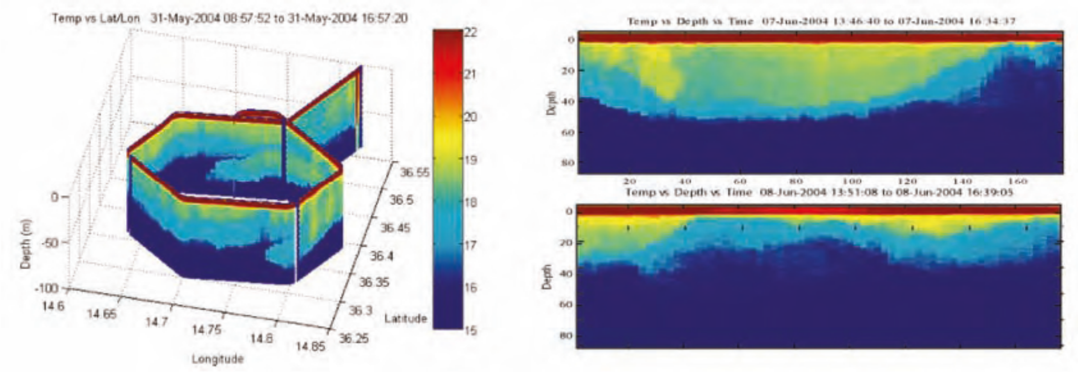

Fig. 2. (Left) Continuous temperature measurement over an exercise track using the ITC cable, (Right) Temperature measurements along another track on consecutive days. Provided by W. J. Comeau, NUWC, USA, during BASE '04.

Environmental volatility is not only concerned with the propagation characteristics of the channel but also with potential changes in the background interference that obscures the received target signal. Fig. 3 provides an example of the latter scenario [3]. Both plots show the matched filter output of the same Linear Frequency Modulated (LFM) pulse, utilized in a noise-limited (left plot) and a reverberation-limited (right plot) environment. The x-axis denotes beam angles with incorporating ping history (broadside at the centre of the plot) and the y-axis denotes detection range. The colour scale spans 25 dB and is the same for both plots. An echo repeater is used as an artificial target. In the noise-limited case the target is clearly detected at broadside. In the reverberation case the target is identifiable (broadside and backward direction) before entering the masking reverberation zone, inside which detection becomes challenging. What makes the comparison between these two cases noteworthy is that, although they had different ship heading they occurred in the same day with moderate spatial (~5nm) and temporal (~3h) separations. It is apparent that if a sonar system is to enhance detection performance in volatile shallow water areas, it must possess mechanisms to enable *in situ* environmental monitoring and real-time system feedback.

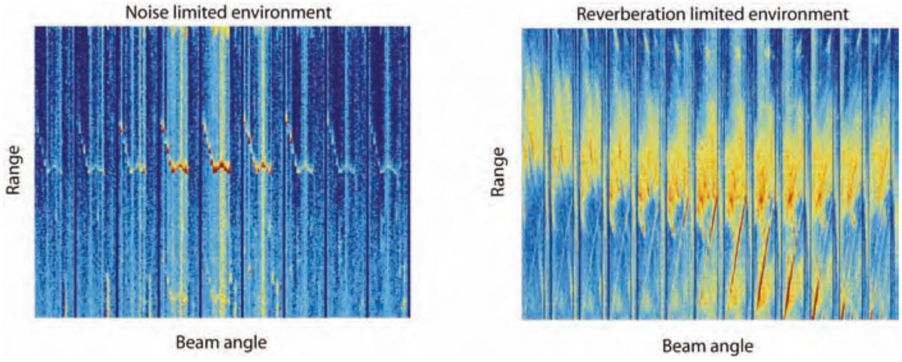

Fig. 3. Matched filter detection output of the same point target in a noise-limited (left) and a reverberation-limited (right) environment

4. BANDWIDTH VS. REVERBERATION SUPRESSION

When frequency modulated signals are used for active detection, the resolution cell, i.e. the area ensonified by a pulse, is inversely proportional to the bandwidth of the transmitted signal, which is the time separation of independent matched filter samples. Therefore, the wider the bandwidth of the pulse the smaller the ensonified segment, which results in an improved performance against reverberation. The theoretical value for reverberation suppression associated with bandwidth increase from *Bx* to *By*, with *Bx* > *By*, is *10·log(Bx/By)*, assuming the same horizontal beamwidth [1]. However, due to environmental conditions and experimental setting, real-life measurements often differ from this theoretical value. Using the low frequency sonar configuration, i.e. the low frequency source and the towed receive line array [5], we calculated the relative reverberation index *a·log(Bx/By)*, where *a* is the reverberation coefficient for three signal bandwidths: 200Hz, 500Hz and 1000Hz. Fig. 4 shows these reverberation measurements for 185 pings. As the standard deviation of the reverberation measurements was more than 2 dB, the calculation of the relative reverberation index is based on the average reverberation levels. The results are summarized in Table 1.

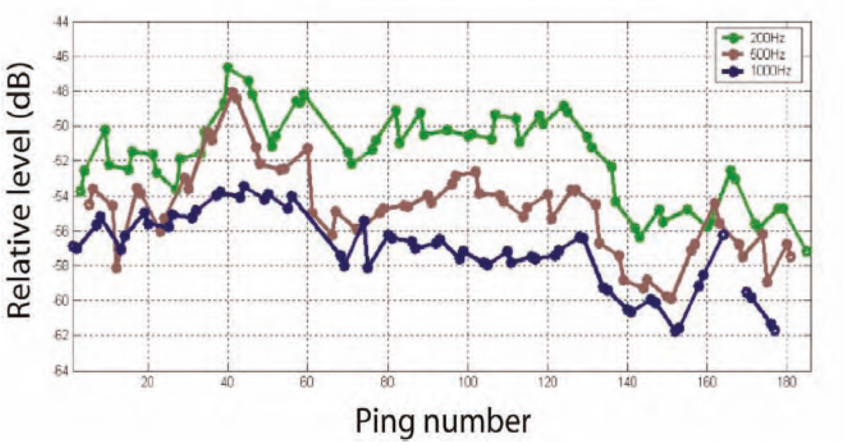

Fig. 4. Measured reverberation level in the absence of any target for three bandwidths:200 Hz (green), 500 Hz (brown), 1000 Hz (blue)

Bandwidths $\left(B_x/B_y\right)$	Average reverberation level (dB)	Reverberation index $a \cdot \log\left(B_x/B_y\right)=$	Reverberation coefficient a
B1=200 Hz B2=500 Hz	-51.69 -54.81	3.12 (dB)	$a = 7.84$
B1=200 Hz B3=1000 Hz	-51.69 -57.15	5.46 (dB)	$a = 7.81$
B2=500 Hz B3=1000 Hz	-54.81 -57.15	2.34 (dB)	$a = 7.77$

Table 1: Measurements of relative reverberation indices using signal bandwidths of 200, 500, and 1000 Hz to estimate the respective reverberation coefficients.

5. CONCLUSIONS

Environmental volatility and reverberation interference constitute two major drawbacks in the performance of active sonar system in coastal, or in general, shallow water areas. Three ways to overcome or reduce the impact of these obstacles are: a) exploitation of broadband pulses to suppress reverberation, b) utilization of a processing chain that allows real time performance feedback related either to the system parameter settings, e.g. bandwidth or centre frequency used, or to the characterization of the background interference, e.g. noise and reverberation levels, clutter, etc., and c) *in situ,* continuous monitoring of the propagation channel conditions through equipment and techniques that do not interfere with or compromise active sonar operations. These three approaches must be used in a coordinated fashion because their independent application in some cases may have negative effects. For example, the use of ultra wide pulses in shallow water but noise-limited areas may even reduce detection performance by providing no gain against ambient noise and, furthermore, over-resolving the target and segmenting its echo. At NATO Undersea Research Centre we are developing an architecture in which system and environmental information, in conjunction with modeling, will form a closed loop to provide system feedback and guidance on how to enhance detection performance in real conditions.

6. ACKNOWLEDGEMENTS

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