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November 2007

Originally published in:

Proceedings of the 2nd International Conference and Exhibition on
Underwater Acoustic Measurements: Technologies and Results, 25-29
June 2007, IACM – FORTH, Heraklion, Greece.

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ADAPTIVE SUB-BAND PROCESSING IN ACTIVE DETECTION AND TRACKING

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Abstract: *Broadband active systems have the potential to increase detection performance in reverberation-limited areas through increased signal bandwidth, i.e. small resolution cell. However, large bandwidth could over-resolve the target and segment the echo energy, as well as raise the false contacts, and therefore increase the false alarm rate. This effect becomes more apparent in shallow water channels that support multi-path propagation.*

One way to overcome this problem is to obtain a priori information regarding the channel characteristics and, based on that, utilize frequency agile methods to enhance detection performance for the particular environment.

More specifically, in this paper we use multipath estimates to predict the most effective bandwidth to be utilized in an adaptive sub-band processing detection algorithm. Based on this prediction, a series of non-overlapping band-pass filters are applied to the full bandwidth complex matched filter output. The results are then combined at the contact level to reduce false alarms and enhance detection performance compared to the full bandwidth.

This methodology is applied to a real data set that includes a surface target and a synthetic submerged target. Comparison between sub-band and full-band processing demonstrates performance enhancement by false alarm reduction while maintaining comparable probability of detection, therefore leading to improved Receiver Operating Characteristic (ROC) curves. The full-bandwidth versus the sub-band processing is also evaluated at the automated tracker level.

Keywords: *Adaptive processing, sub-band processing, active target detection, Receiver Operating Characteristic (ROC), tracking, multipath.*

1. INTRODUCTION

It is well known in the operational and scientific sonar communities that active sonar performance in the littoral is degraded by high levels of clutter and diffuse reverberation [1]. Reverberation can mask target echoes, thus reducing the probability of detection (PD), while clutter may induce false alarms. The response to the reverberation challenge was the introduction of low frequency broadband systems, which enhance sonar performance by means of resolution cell reduction. Consequently, it is now a common practice to use the full bandwidth allowed by the sonar system when reverberation-limited conditions occur. However, this may not always be the optimal solution, as the frequency characteristics of the environment and the target are not accounted for [2]. Furthermore, as the bandwidth increases, we may have diminishing returns in sonar performance due to target over-resolution, i.e. the target's echo is segmented, and therefore the signal-to-background ratio (SBR) decreases. Target over-resolution is amplified in case of multipath propagation. On the other hand, in high clutter areas, this over-resolution effect may significantly raise the false alarm rate, which impedes target detection and tracking. These two problems may be addressed through the development of adaptive sonar systems capable of adjusting to different environmental conditions [3]. Target detection in shallow water can be improved by exploiting environmental knowledge, in conjunction with validated models, to predict optimum sonar settings (e.g. bandwidth, central frequency, pulse duration, etc.).

In this paper we focus on bandwidth adaptation. The predicted optimum bandwidth is identified via a series of band-pass filters which divide the energy into smaller sub-bands with optimum width. This approach, called *sub-band processing*, may be applicable to baseline sonar systems without built-in signal processing capability. Previously [4], sub-band processing was applied to data sets that contain fixed targets of opportunity, such as wrecks and clutter points. Here it is applied to mid-water column and surface targets and the performance analysis is evaluated at both the detection and the automated tracker levels.

2. BANDWIDTH ADAPTATION BY MEANS OF SUB-BAND PROCESSING

In general, the optimum bandwidth in a given environment can be predicted by performing an exhaustive search for the bandwidth which maximises the desired measure of performance, such as SBR or signal excess. Here we propose an alternative methodology in which the search for the optimum bandwidth is linked to the channel characteristics, and in particular to target spreading due to multipath. Recently derived analytical expressions [5] are used to predict channel spreading, which was found to be constant for ranges longer than a few kilometres. For example, in a typical shallow water environment with silt bottom, the time spreading of a target at long ranges is of the order of 0.1s, corresponding to a bandwidth of 10Hz. Experience indicates that sub-band processing may be based on sub-bands of the order of 50Hz.

The two main stages of the proposed sub-band processing technique are (a) sub-band filtering and (b) contact processing. Sub-band filtering consists of passing the complex, full bandwidth matched filter output to a bank of N contiguous and non-overlapping band pass filters whose widths are equal to the predicted optimum bandwidth. The band-pass filtered data are sent to the detector. The resulting N sets of contacts can be passed directly to the automated tracker which considers them as data coming from N independent, co-

located sensors working in different bands. Alternatively, the N sets of contacts can be pre-processed before being passed to the tracker. Two alternative scenarios may occur. If we know that some frequency regimes are more effective than others, we can select the best sub-bands and remove the poorly-performing ones [3]. If no *a priori* information is available, all sub-bands are taken into account and fused to generate a single set of contacts. The main goal of contact fusion is to remove contacts which are not persistent over sub-bands. In this process, it is hypothesized that contacts associated with real targets are more persistent over sub-bands than contacts generated by noise or random combinations of clutter returns [4]. As a consequence, contact fusion, if successful, decreases the false alarm rate (FAR) without negatively affecting PD. The simple fusion algorithm proposed here consists of mapping the contacts to a coarse time/bearing matrix according to their mean arrival time and mean bearing. The cell size is set equal to the beam width in the beam direction by five times the time resolution after pulse compression. After mapping, for each cell location the number of contacts over sub-bands is counted. If this count is higher than a preset threshold (called *persistence threshold*), the strongest contact in the cell is retained. If the persistence threshold is not crossed, the cell is cleared and all the corresponding contacts are removed. Typical values of the persistence threshold range from 15% to 50%. This kind of contact fusion (also called *contact sifting* [4]) has the advantage of being easy to implement, but there are some known limitations. Due to localization uncertainties, it is possible that contacts generated by different scatterers are mapped to the same cell (*false associations*). On the other hand, contacts generated by the same scatterer may be mapped to different cells and therefore not associated (*missed associations*). This indicates that the choice of the cell size is critical: if the cells are too large, the probability of false association increases; if the cells are too small, the probability of missing association increases.

3. EXPERIMENTAL RESULTS

Sub-band processing was tested on experimental data collected during the BABO'06 sea trial. This experiment, planned and executed by NURC, a NATO Research Centre located in La Spezia, Italy, in collaboration with the German laboratory FWG, took place on the Malta Plateau, a shallow water area between Sicily and Malta. The main assets which participated in BABO'06 were the NATO Research Vessel (NRV) Alliance, towing the sonar system, and the RV Planet, towing an echo-repeater (E/R) which is a synthetic target with controlled target strength.

The signals transmitted were 1.0- to 1.5KHz-bandwidth linearly frequency modulated (LFM) upsweeps. The full bandwidth analysis of the data showed that the E/R was detectable in all pings, due to favourable propagation conditions and to good sonar performance. Furthermore, most of the data also contained surface contacts from the RV Planet. These contacts were due to the particular hull structure of the vessel (swath technology) and are generally characterized by SBR values much lower than contacts from the E/R. Here, we focus on one run for which the distance between the sonar system and the target was constant. The optimum bandwidth proposed by the analytical formulae for this environment is 50Hz. Additional sub-bands investigated for comparison are 100Hz, 200Hz and 500Hz.

3.1. Detection results

Full-bandwidth processing and sub-band processing are compared here by means of ROC curves, generated for both the E/R and the RV Planet as targets of interest. Examples of the results are shown in Fig. 1, for the surface contact and considering data with a full-bandwidth equal to 1.5KHz.

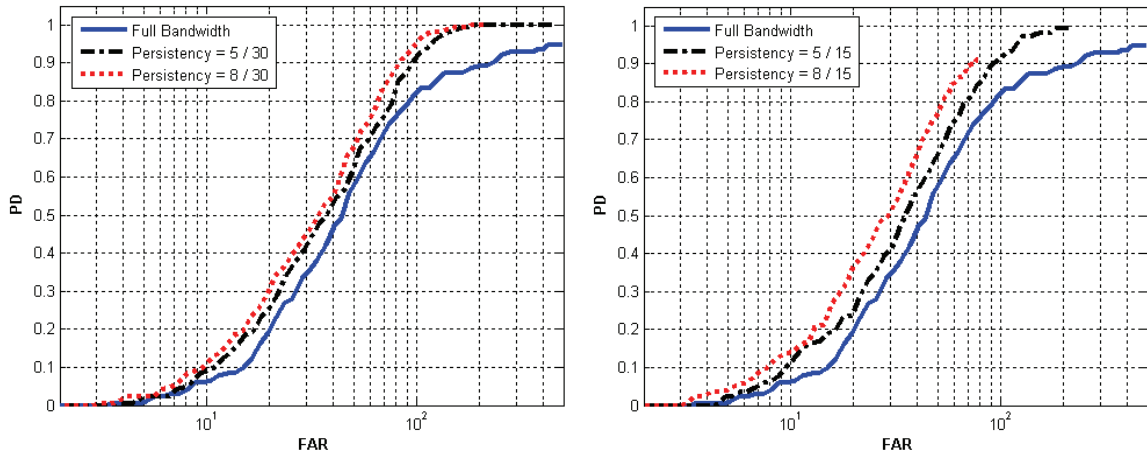


Fig.1: ROC curves for full bandwidth (1.5KHz) and sifted contacts for RV Planet: sub-bands of 50Hz (left) and sub-bands of 100Hz (right).

For sub-bands of 50Hz (30 sub-bands) and sub-bands of 100Hz (15 sub-bands), the analysis of the ROC curves shows that sub-band processing leads to a general reduction of the FAR (the higher the persistency threshold, the lower the FAR) thanks to contact sifting. At the same time, there is a moderate increase in PD, which is more evident when 50Hz sub-bands are used.

3.2. Tracking results

Four automated tracking architectures are investigated [6]: (1) *full-band*: tracking of contacts generated by conventional full-band processing (a single contact file per ping); (2) *single-band*: tracking of contacts for a single sub-band from each ping; (3) *contact sifting*: sub-band tracking of fused contacts based on a persistency criterion; (4) *sub-band centralized*: the tracker is applied in a single stage to the entire set of contacts from all the sub-bands. The tracker outputs are shown in Fig. 2. The blue line represents the Alliance’s track. The two horizontal lines are the RV Planet (closer to Alliance) and the E/R. In all cases, we note significant benefit of automated tracking in terms of the dramatic reduction in false contacts, with comparable detection levels. Case 1 is characterized by the best track hold and no track fragmentation, but by a high false track rate as well. False tracks are significantly reduced for single sub-band tracking (case 2), but in this case track hold is poor and track fragmentation is high. This indicates that single sub-band contacts are of poor quality if compared to full-band contacts. Contact sifting (case 3) yields good performance in terms of track hold and track fragmentation, with an interesting reduction of false tracks compared to case 1. Finally, centralized tracking (case 4) is characterized

by the highest false track rate, as well as high levels of track fragmentation. This indicates that higher data rates do not necessarily lead to improved performance.

In summary, full-band processing and contact sifting proved to be the most robust architectures.

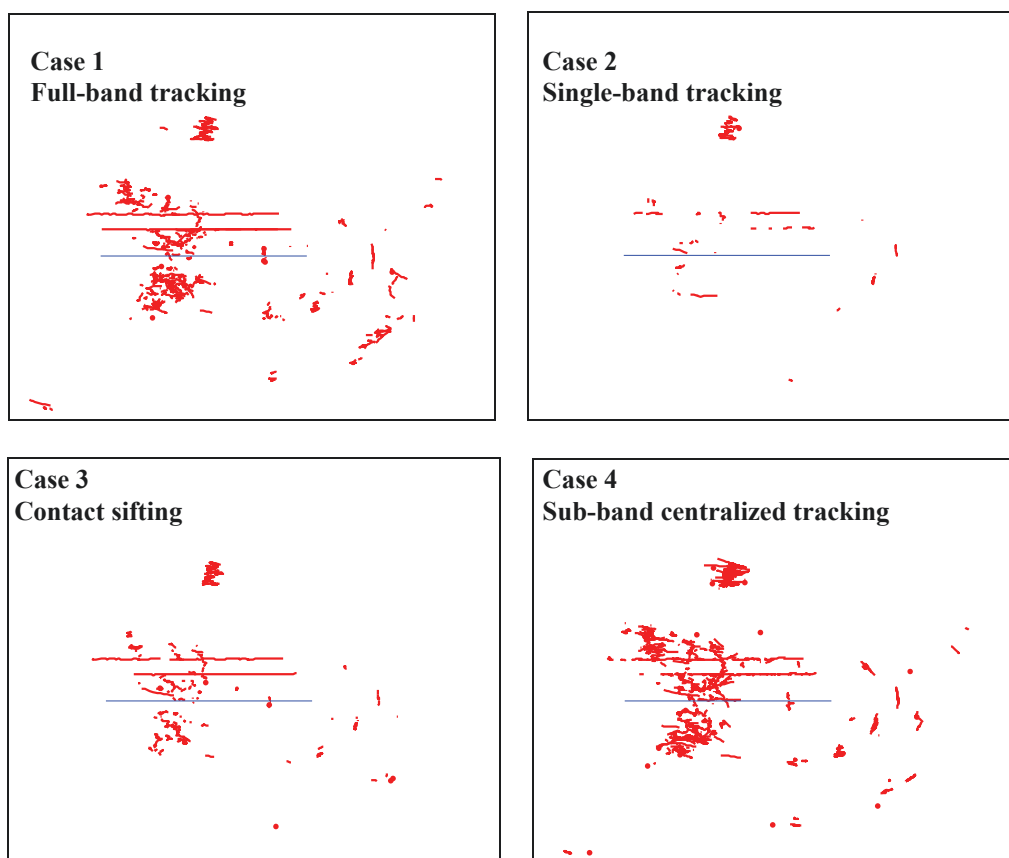


Figure 1: Tracker outputs for the four architectures presented in section 3.2.

4. CONCLUSIONS

In this paper we have investigated the potential of sub-band processing to improve target detection and tracking in shallow water. At the detection level, significant performance improvement can be achieved, mainly thanks to the reduction in false alarm rate, while preserving comparable probability of detection. The results are evaluated in terms of ROC curves.

The primary results of our analysis regarding tracking of sub-band data are: (a) automated tracking provides significant benefit to the active sonar signal and information processing chain; (b) sub-band processing offers many alternatives for contact fusion and tracking schemes; at present, contact sifting appears to provide the most competitive alternative to full-band processing; and (c) improved detection probabilities come at the cost of increased false object rates.

Areas of further investigation are: (a) identification of suitable contact persistency criteria; (b) optimization of the cell size of the association matrix used for contact sifting; (c) sub-band contact fusion techniques alternative to contact sifting to exploit *a priori* information; (d) modelling the effect of very high data rates on sonar performance.

5. ACKNOWLEDGEMENTS

The content of this document pertains to work performed under Projects 4C3 (Broadband Environmentally Adaptive Sonar Concept) and 4A3 (Multistatic Sonar) of the NURC Programme of Work, in collaboration with Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik (FWG, DEU). The authors would like to thank EV2 S. Bayet and EV2 D. Forestier, of the French Naval Academy, for their fundamental contribution to this work.

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Document Data Sheet

<i>Security classification</i>		<i>Project No.</i>
<i>Document Serial No.</i> NURC-PR-2007-014	<i>Date of Issue</i> November 2007	<i>Total Pages</i> 7 pp.
<i>Author(s)</i> Baldacci, A., Haralabus, G., Coraluppi, S., Prior, M.		
<i>Title</i> Adaptive sub-band processing in active detection and tracking.		
<i>Abstract</i> .		
<i>Keywords</i>		
<i>Issuing Organization</i> NURC Viale San Bartolomeo 400, 19126 La Spezia, Italy [From N. America: NURC (New York) APO AE 09613-5000]		Tel: +39 0187 527 361 Fax: +39 0187 527 700 E-mail: library@nurc.nato.int