IMPROVED ACTIVE SONAR TACTICAL SUPPORT BY THROUGH-THE-SENSOR REA

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Abstract: *Reverberation is a problem for active sonar operating in shallow waters, reducing detection probabilities and introducing false alarms. Within the European Defence Agency project Rumble-2, a demonstrator system has been developed for "through the sensor" measurement of the bottom parameters needed to predict active sonar detection performance. An operational low-frequency active sonar is used along with a real-time inversion method. The demonstrator is a self-contained unit that reads sonar data without interfering with the on-going sonar operation. Several sea trials have been performed demonstrating its good performance. The inversion results are consistent with ground truth. Moreover, similar results are obtained for trials in the same area with quite different environmental conditions. The demonstrator tool is based on several simplifying assumptions, such as range independence and a homogeneous half-space bottom. Off-line studies, made with a sediment layer, show that the effects of a range dependent bathymetry are small in the survey area. In addition, it is shown that inversion for a grain size parameter and utilization of regression formulas for sediment sound speed and absorption are useful for stabilizing some inversion parameters.*

Keywords: *Reverberation, inversion, mean grain size, rapid environment assessment (REA).*

1. INTRODUCTION

Accurate seismo-acoustic parameters of the seabed are required to produce reliable predictions of active sonar detection ranges. The bottom parameters of main interest are sediment sound speed, density, and absorption, and the Lambert parameter (or some other measure of the back-scattering strength due to bottom roughness). Validated techniques are needed to estimate these parameters. This estimation should preferably be performed in real-time, to enable tactical support at on-going surveillance operations.

The EDA (European Defence Agency) project Rumble-2 aims at developing such techniques. A frigate with a low-frequency towed-array active sonar system (Captas from Thales Underwater Systems) is used. The system operates with HFM (hyperbolic frequency modulation) pulses centred at about 1.5 kHz, and a triplet receiver array allows left-right discrimination. After beam-forming in the broad-side direction and matched filtering, the time series from each sonar ping is transferred to the inversion system. Global optimization methods are used to minimize a cost function representing the difference between observed and modelled reverberation time traces. Those bottom parameters that provide the best match are selected, displayed, and stored. As the ship moves on, more and more of the sea bottom is covered, and bottom charts can be displayed for the estimated parameters.

A demonstrator system has been developed and successively used in several sea trials in the North Sea outside Norway. Using the estimated bottom parameters, current detection and counter-detection distances for the operation can be estimated with a standard sonar support system. “Through the sensor” REA (rapid environment assessment) capability is achieved, in the sense that the additional data processing does not interfere with the on-going surveillance sonar operation,.

The plan of the paper is as follows. A brief description of two of the sea trials is given in Sec. 2. The inversion method and actual inversion results are presented in Secs. 3 and 4, respectively. These results have been produced off-line, relaxing several simplifying assumptions made in the demonstrator itself: actual bathymetry data are used, and sediment thickness is included as an additional parameter. Most importantly, however, a mean grain size parameter (M_z, in ϕ units) is introduced to stabilize the inversion. Specifically, sediment sound speed, density, and absorption are determined as functions of M_z by known regression relations. Conclusions are formulated in the final Sec. 5.

2. SEA TRIALS AND ENVIRONMENTAL INFORMATION

Four sea trials have been performed, two of them, ST2 and ST4, in the North Sea west of Bergen. The measurement geometry was bistatic with a horizontal offset of about 500 m between the source and the receiver array. The source and receiver depths were about 110-120 m during ST2, and 60-100 m during ST4.

The Bergen area was extensively surveyed by FFI in 2003-2008. Single beam echosounder data at 38 kHz were collected and used to classify the seabed [1]. The classes were identified by taking bottom samples to range from mainly clay to sand with varying amounts of gravel [2], see Fig. 1. In ϕ units, the mean grain size for sand typically varies between −1.0 and 4.0, while the grain size for silt is between 4.0 and 9.0.

The trial area is relatively flat, with bottom depths between 260 and 320 m. ST2 was performed in June 2010, with a sound speed profile that was mildly downward refracting below a surface duct with a thermocline at depth 50 m. The environmental conditions during ST4, performed in October 2010, were different, with an irregular sound speed profile and high wind speeds, for example.

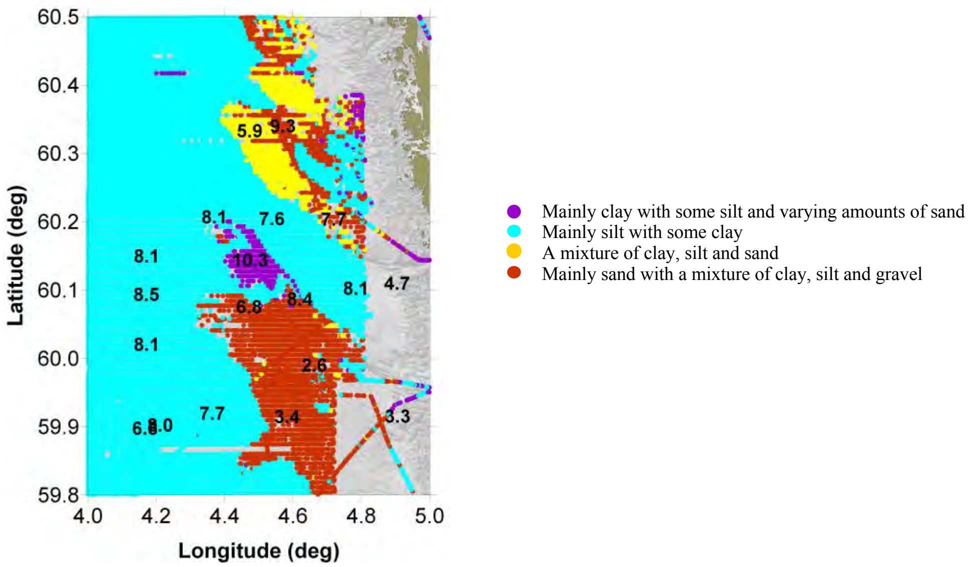

Fig.1: Classification of the Bergen area into four seabed types. The numbers indicate, in ϕ units, the median (not mean) grain size values, as measured from bottom samples [2].

3. INVERSION METHOD

A global optimization method, differential evolution, is used to determine the bottom parameters that provide the best match between the measured and modelled reverberation time traces. A fast ray model is used for the forward computations. The bottom parameters are the Lambert back-scattering parameter and a number of parameters that control the reflection coefficient at the bottom: sound speed c, density ρ, and attenuation α of the sediment as well as the underlying bedrock, and sediment thickness. Reverberation data do not constrain all these parameters to unique values, however. Nielsen and Harrison [3] combined reverberation and propagation data to stabilize the inversion, while van Vossen et al. [4] presented values of the reflection coefficient at a certain characteristic grazing angle (10^o).

The present paper uses another way to reduce the ambiguity problems. The mean grain size M_z is used as a common descriptive parameter. Relevant regression relations exist, that go back to work by Hamilton and Bachman. They are based on M_z, in ϕ units, and they are depicted in Fig. 2. The relations are valid in the mid-frequency regime (1-10 kHz), for the upper few metres of the seabed, and they can be found in Table 4.18 of [5]. The indices $_w$ and $_{sed}$ in Fig. 2 indicate the values in the water (just above the bottom) and in the sediment for the indicated parameter. The regression relations are here used as hard constraints (i.e., deterministic relations) at the inversion. In essence, each parameter triplet (c_{sed}, ρ_{sed}, α_{sed}) is replaced with a single M_z parameter. An additional advantage is that ground truth values for the grain size are available. Mean grain size values could not be computed from the grab samples, but related median values are shown in Fig. 1.

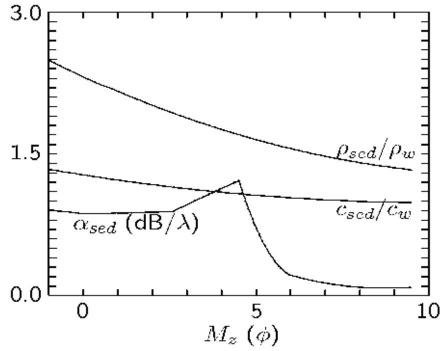

Fig.2: Regresson relations for sediment sound speed c_{sed}, density ρ_{sed}, and absorption α_{sed}. The independent parameter is mean grain size M_z, in ϕ units.

The search region for M_z is taken as $0.0\ \phi < M_z < 9.0\ \phi$ .The Lambert parameter μ, for the back-scattering from the bottom, is also included in the inversion, with search interval [−40.0 dB, 10.0 dB]. A third inversion parameter is the sediment thickness h, with search interval [0.01 m, 25 m]. The part of the bottom below the sediment layer is modelled as a homogeneous half-space with sound speed 1950 m/s, density 2.1 g/cm^3, and absorption 0.4 dB/wavelength. Its solid character is incorporated by using 600 m/s and 1.0 dB/wavelength for shear-wave sound speed and absorption, respectively. Numerical experiments show that these half-space parameters are not very sensitive.

4. INVERSION RESULTS

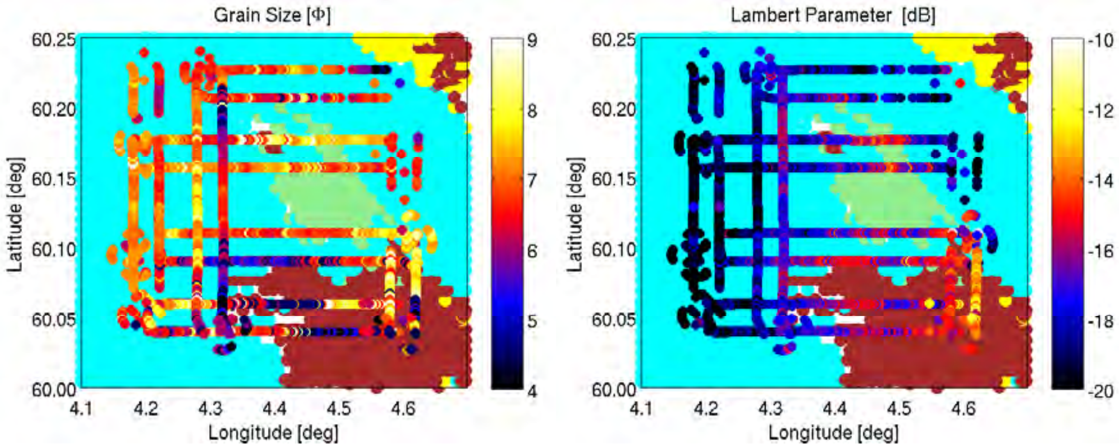

Fig. 3:ST2 inversion results for mean grain size M_z in ϕ units (left panel) and Lambert μ in dB (right panel). Each circle represents a port or starboard ping result, displaced 1 km from the track of the frigate. The ground truth bottom classification is also indicated, with brown, blue, and green for mainly sand, silt, and clay, respectively.

The mean grain size M_z and Lambert μ results for ST2, performed in June, are shown in Fig. 3. Each track sailed by the frigate is represented twice, with port and starboard ping inversion results denoted by circles at about 1 km from the track. The panels of Fig. 3 also show relevant parts of the bottom classification from Fig. 1. As expected, low M_z values mainly occur in the sandy southern part, particularly for the beams looking south, which is consistent with the numerical values in Fig. 1. High Lambert μ values of about −13 dB appear in the sand, while low values of about −20 dB appear in the silty western part.

The results from ST4 are shown in Fig. 4. Despite the quite different environmental conditions, the main features from the ST2 results are repeated. Low M_z values appear for south- and east-looking beams in the sand, cf. the ground truth values in Fig. 1. The highest Lambert μ values appear in the south-east part where sand dominates.

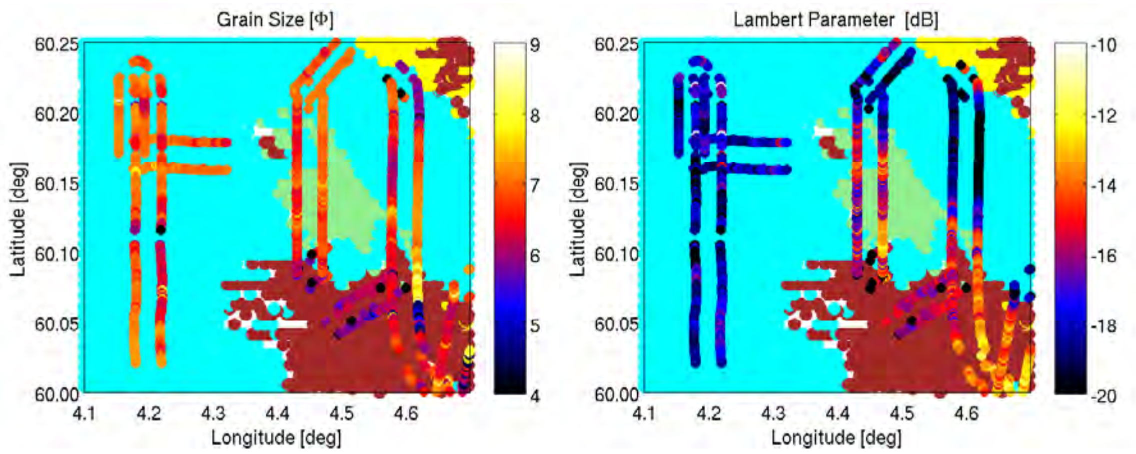

Fig. 4: Inversion results as in Fig. 3 but for ST4, performed in October.

The inversion computations provided modelled reverberation time traces with very good fit to the measured ones. In general, the rms (root-mean-square) misfit is between 0.5 and 1 dB. The third inversion parameter, sediment thickness *h*, typically varies between 2 and 7 m. (Some larger values also appear for ST4, but they may be less certain because of a larger misfit.) The results presented have been produced with range-dependent computations, taking the actual bottom bathymetry into account. Range-independent computations give very similar results, however.

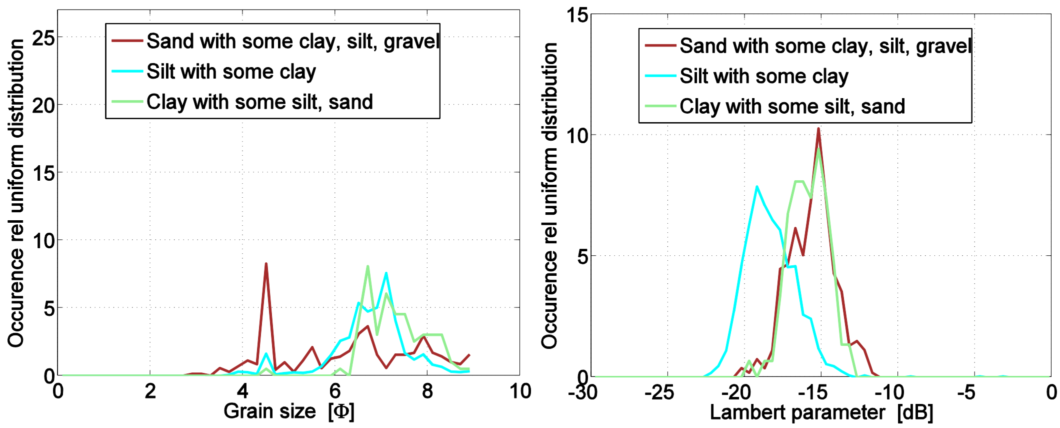

Fig. 5: Distributions of the ST2 inversion results from Fig. 3, categorized by ground truth bottom type. The scale for the vertical axes is such that a uniform distribution would be represented with the value 1.

The ST2 results of Fig. 3 are presented as distributions for each ground truth bottom type in Fig. 5. The M_z values range from about 4.0 to 9.0 (in ϕ units), and the distributions for the three bottom types show interesting differences. Again, the lowest values are obtained for sand. Concerning the Lambert parameter, rather similar distributions are obtained for sand and clay, whereas the distribution for silt is shifted to lower values corresponding to less back-scattering. This is consistent with inversions reported in [4].

Fig. 5 also shows regions dominated by sand with higher M_z values, similar to those for the silt and clay regions. A possible reason is the limited resolution: each circle in Fig. 3 actually represents an inversion carried out over a distance of up to 7.5 km (corresponding to a two-way traveltime of 10 s) from the frigate track. For example, the yellow circles at longitudes of about 4.5°, for beams to the north from the track at latitude 60.05°, may appear because areas dominated by silt as well as clay are involved.

Fig. 6 shows analogous distributions for the ST4 results. Except that the peak for sand at about 4.5 ϕ for M_z is less prominent, the agreement to Fig. 5 is satisfactory.

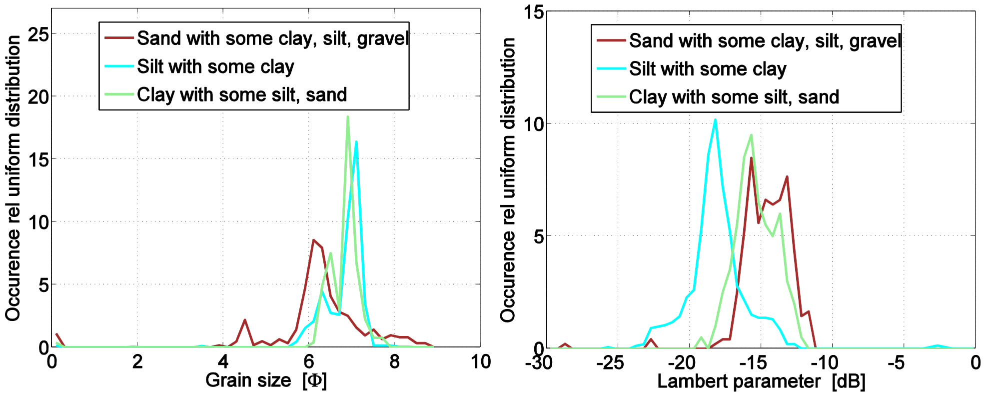

Fig. 6: Distributions of the ST4 inversion results from Fig. 4, for the bottom types.

5. CONCLUSIONS

A demonstrator system has been developed for real-time estimation of bottom parameters using a low-frequency active sonar. Successful sea trials have been made in the North Sea, providing results consistent with ground truth under different environmental conditions. Extensive off-line inversions show

- only small effects of bistatic geometry and varying bathymetry in the survey area, giving support to simplifying assumptions made in the demonstrator
- potential for utilizing empirical regression relations to replace sediment sound speed, density, and absorption by a mean grain size M_z parameter at inversion.

ACKNOWLEDGEMENTS

This work has been performed within the EDA (European Defence Agency) project Rumble-2. Partners are TUS (France), FFI and KDS (Norway), TNO (The Netherlands), and FOI (Sweden). Funding is provided by the Ministries of Defence of the four nations. The sea trials were excellently hosted and supported by the Royal Norwegian Navy.

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