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AN IMPROVED PROCESSING CHAIN FOR MATCHED FIELD TRACKING

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Matched Field Processing (MFP) for range/depth source localisation has been applied successfully to vertical arrays of hydrophones for more than 10 years. However, these arrays are awkward to deploy. On the other hand, horizontal towed arrays offer little or no vertical aperture, making range and depth localisation an inspiring challenge. This shortcoming, combined with the frequent problem of environmental mismatch and hostile conditions of shallow water (increased noise levels and interfering sources) results in severe degradation of the MFP ambiguity surfaces, thus preventing source localisation.
This paper reports on our research effort for the application of MFP to short towed arrays (32λ at 2kHz). A realistic scenario has been simulated, involving a target source and additional interfering noise sources. A normal mode model is used for the modelling, and environmental mismatch is introduced. Inverse beamforming is used to remove the interfering sources at hydrophone level, prior to MFP. A multiple target tracker is then used to distinguish sidelobes from actual target detections over a series of snapshots. Application of this method on simulated data shows encouraging results.

1. INTRODUCTION

Detection, Classification and Localisation (DCL) for anti-submarine-warfare in shallow waters is typically performed by using a Low Frequency Active Sonar (LFAS). These systems are however not deployable by all platforms or in all conditions. Some tactical situations demand discreet operations and therefore a passive sonar system. The operational towed arrays used for LFAS can easily be used in passive mode but offer a relatively short aperture. This paper presents our efforts to develop an advanced passive processing chain for those arrays, with the goal of localising a target in bearing, range and depth.

Matched Field Processing with a horizontal towed array presents several problems, some of which are not encountered when using a vertical array. To begin with, the measurements are perturbed by the tow ship itself, which acts as a very close and loud interferer. Secondly, although MFP results are very sensitive to errors in the array tilt, the actual tilt is difficult to estimate as it is influenced by the array's tow point motion. Furthermore, like in any MFP localisation situation, a poor knowledge of the environment rapidly degrades the performance. Finally, the ambiguity surfaces from horizontal array data feature many sidelobes, intrinsic to the poor (vertical) spatial sampling of the sound field.

Addressing these issues, we propose an improved multistage processing chain. In the first step, environmental and geometrical information is collected for an initial estimate of the geo-acoustic environment and experimental geometry. The array geometry is estimated using a model-based Kalman technique. Pressure fields from array data are 'cleaned' of tow ship noise by means of Inverse Beamforming (IBF). Next, Matched Field Inversion (MFI) is applied in order to improve the geo-acoustic parameters of the seabed. The cleaned pressure fields are then used together with the improved environment and geometry in a Bartlett Matched Field Processor. Finally, the generated range-depth ambiguity surfaces are fed to a Multiple Target Tracker (MTT) in order to discriminate the target main lobe from spurious peaks.

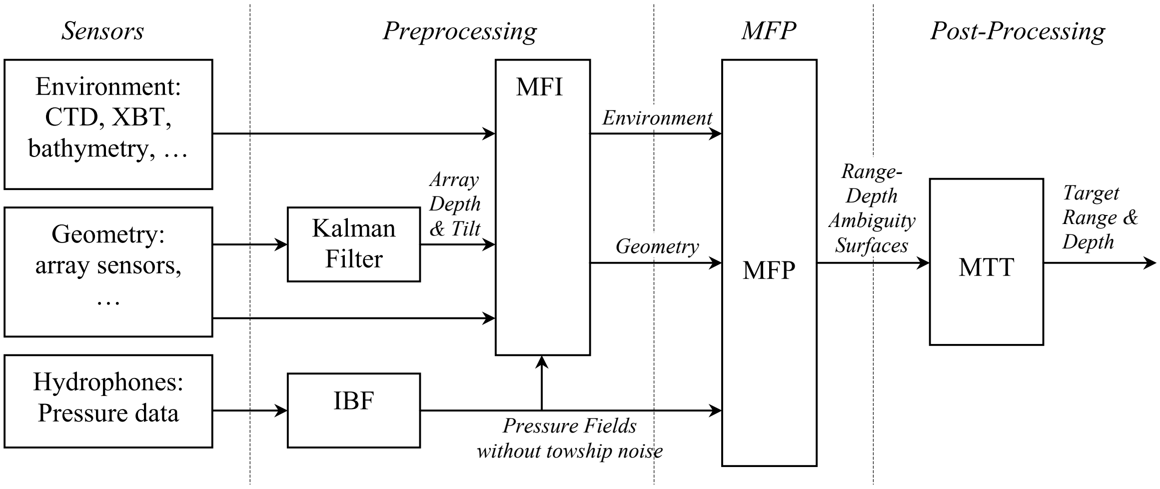

Fig 1. Processing chain

The processing chain was successfully applied to simulated data, in preparation to processing of experimental data from an experiment in the Mediterranean Sea in 2003. During this experiment, multi-tone signals in the frequency range 200-700 Hz were received on a towed horizontal array. The source range varied from 2 to 20 km along a continuous track with a water depth of approximately 700 m.

In the following sections, the various blocks of the processing chain are described in detail. Subsequently, application of the method to simulated data is described and results are presented.

2. THE PROCESSING CHAIN

2.1. Tow Ship Cancelling

Successful target localisation with MFP hinges on the assumption of a *single* source in the measured data. When using a towed array however, there will always be an additional source present in the form of tow ship noise. The weak signal from the target can be severely perturbed, especially because the array is normally towed relatively close to the ship (about 200 m), within the Fresnel's range. As a result, not only the forward bearings are contaminated with machinery noise, but also the rest of the beampattern has to suffer from tow ship noise sidelobes. It is impossible to detect any target in the resulting ambiguity surfaces.

For successful cancelling of the strong interference of tow ship noise, we applied an Inverse Beamforming (IBF) algorithm, described in [1]. This technique allows removal of a source by subtracting its signal from hydrophone data. The target's bearing and amplitude for each frequency must first be estimated. Considering an interferer radiating at frequency f_i with an amplitude $\tilde{A}_i$ at bearing $\tilde{\theta}_i$, inverse beamforming consists of zeroing the signal coming from this direction in the beam pattern

$$S_{n,IBF}(f_i) = S_n(f_i) - \tilde{A}_i \exp\left(jnk_i\delta_x \sin\tilde{\theta}_i\right) \tag{1}$$

where $k_i = 2\pi f_i/c$, c being the sound speed in water, δ_x the spacing between hydrophones and S_n the pressure field at hydrophone n.

For the practical implementation of IBF, we first apply conventional beamforming to the considered pressure fields in order to estimate the bearing and amplitude of the tow ship noise. A signal with the estimated amplitude and direction is then subtracted from the hydrophone signals, simultaneously removing the interference mainlobe and sidelobes in the beampattern.

2.2. Array geometry

Another problem concerns the receiver geometry during the experiment, in particular the tilt estimation of the towed array. The array used by TNO-FEL during trials is fitted with two pressure sensors front and aft of the hydrophone section. These sensors record the instantaneous height of water column above, which means that surface waves form a severe source of error for the depth measurements.

The pressure sensors are not situated at the extremity of the acoustic section of the array. A simplistic way to estimate the tilt assumes a rigid array and directly uses the sensor measurements. This approach however, can lead to severe estimation errors, as is shown in Fig 2. It is preferable to estimate the shape of the whole array section between the sensors, even if one assumes a straight acoustic section. A model-based solution to this problem is proposed in [1], where the behaviour of the array, towed at constant speed, is described by the Paidoussis equation. An approximate solution to this equation (the water pulley model) is expressed as a state-space model, which we implemented in combination with a linear Kalman estimator to estimate the actual shape of the array.

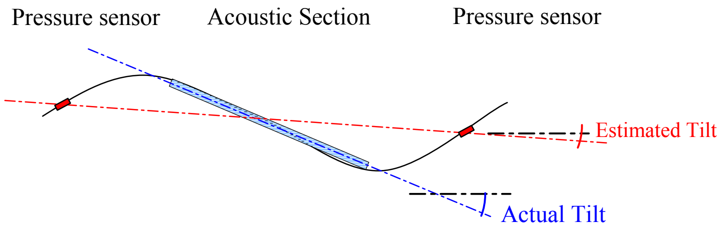

Fig 2. Array tilt estimation.

2.3. Acoustic Inversion and Matched Field Processing

During operational situations it is generally impossible to acquire precise knowledge of the acoustic environment. Matched Field Inversion (MFI) can then be used to estimate geo-acoustic and geometric parameters. Our inversion method consists of a standard Normal Mode model for forward modelling [3][4], while a relatively new method is used for global optimisation, called Differential Evolution (DE)[5]. For a detailed description and results see [6].

Next, the ‘cleaned’ pressure fields and improved geo-acoustic environment and geometry are used to generate range-depth ambiguity surfaces with MFP. A Normal Mode model is used in combination with a vectorised implementation of the incoherent multi-frequency Bartlett processor [4][7].

2.4. Matched Field Tracking

The MFP ambiguity surfaces are saturated with side lobes and a simple maximum search is not enough to pinpoint the range and depth of the target. However, by looking at a series of ambiguity surfaces generated at discrete time intervals, it is possible to detect the relative movement of the target and discriminate it from sidelobes. A Multiple Target Tracker is used, based on a Kalman filter [8].

3. SIMULATIONS

In order to test the developed processing chain, simulated data were generated using a Normal Mode model. The previously mentioned experimental configuration was modelled, where multi-tone signals in the frequency range 200-700 Hz were received on a horizontal towed array, consisting of 64 hydrophones with 0.36 m spacing and 3° array tilt. A water sound speed profile measured during the 2003 trial was used, featuring a duct around 100 m.

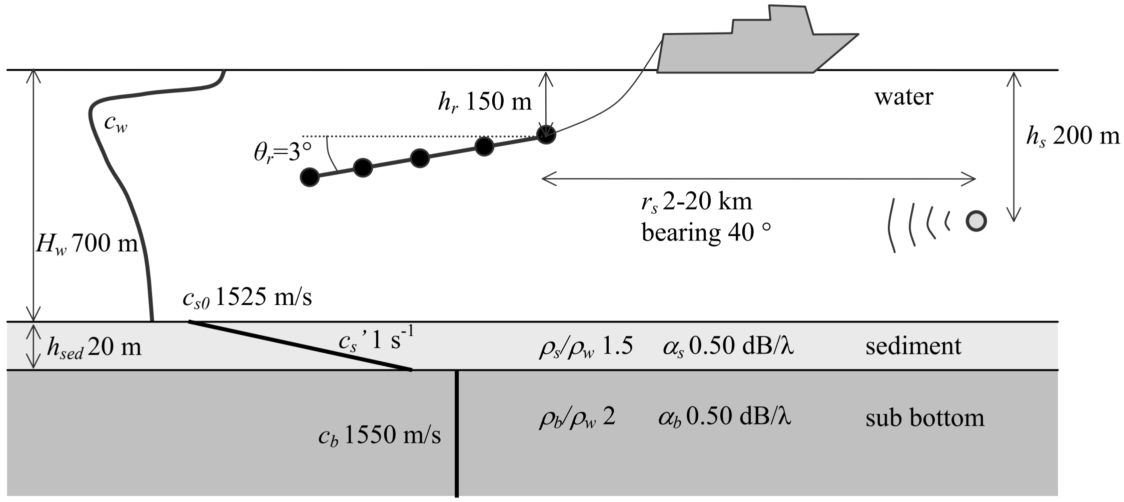

Fig 3. Model configuration.

Realistic tow ship noise was added to the data, which was subsequently removed using IBF. Separately, the simulated data were used to for MFI. After that, fields were generated for numerous source ranges varying from 2 to 20 km and a constant bearing, along a continuous track.

3.1. Results

The effect of IBF on the quality of the ambiguity surfaces is profound. Before IBF, the target cannot be localised due to the interfering signal and the average levels of the surfaces are very low. In addition, there is hardly any contrast (low standard deviation) in the images. Application of IBF removes the interference, thus raising the overall levels of the ambiguity surfaces and improving image contrast as summarised in Table 1. A (local) maximum appears at the expected target position, making tracking possible.

	Average energy	Standard deviation	Maximum energy	Depth error	Range error
Before IBF	0.054	0.0045	0.056	162 m	479 m
After IBF	0.88	0.07	0.94	5 m	3 m

Table 1: Typical results of IBF on ambiguity surfaces.

The MTT is able to track the target all along its simulated path, except around a target distance of 12 km, where localisation is very difficult and the track is lost for a short period of time. All other contacts are not tracked for more than 5 snapshots, yielding only short non persistent target tracks.

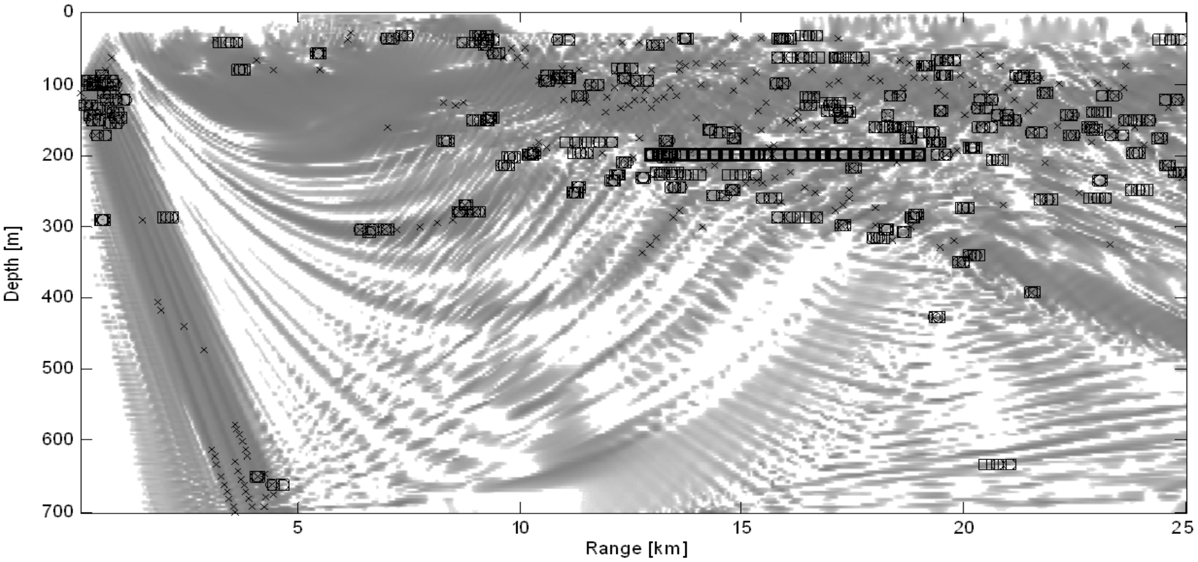

Fig 4. Estimated tracks overlaid on one of the ambiguity surfaces. The crosses represent the contacts in the current ambiguity surfaces, the squares represent a track history. The longest track (depth ~200m, range [12 km-18 km]) is the track of the target.

4. CONCLUSIONS

Matched Field Processing with a short horizontal array is a challenging subject, where no single technique can result in unambiguous target localisation. Only by combining and integrating various techniques is it possible to successfully localise and track a target.

The developed processing chain proves to be very powerful in this way. Although it is impossible to localise a target in the original (simulated) data, the output of the processing chain yields a single and stable target track. In the near future, we will try to apply the technique on experimental data.

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