Proceedings of the Seventh European Conference on Underwater Acoustics, ECUA 2004
Delft, The Netherlands
5-8 July, 2004

DETECTION CLASSIFICATION AND LOCALISATION OF MARINE MAMMALS USING THE PASSIVE ACOUSTIC CAPABILITIES OF AN LFAS SYSTEM

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World-wide a concern is emerging about the influence of man-made sound on marine life and more particularly marine mammals, who fully depend on sound in their natural behaviour. High power active sonars systems like Low Frequency Active Sonar (LFAS) are at stake. These systems, designed for long range detection of submarines, consist of a powerful source and a towed array receiver. Incidents with marine mammals could be avoided if these receivers, dedicated to detection of submarine echoes, were also equipped with Detection, Classification and Localisation (DCL) capabilities of marine mammals. In this paper the development of a (prototype) DCL system for the TNO-FEL LFAS array (named CAPTAS) is described. The DCL algorithms are applied to simulated and sea trial data. Results are promising for detection and encouraging for classification and localisation.

1. INTRODUCTION

To avoid exposure of marine mammals to dangerous sound levels detection, classification and localisation of these mammals within the danger zone of a sonar system is essential [1]. The problem with passive DCL of marine mammals is the wide variety of produced sounds. The duration and frequency bands have a large spread (ranging from calls from baleen whales with frequencies of 10-20 Hz, to clicks from porpoises up to 160 kHz).

In this paper we focus on passive DCL of marine mammals using an LFAS array. The LFAS array used is the TNO-FEL CAPTAS triplet array with a capability for instantaneous left-right discrimination through the use of hydrophone triplets. The array operates in the frequency band from 10 to 2080 Hz [2]. The latter is rather restrictive.

For detection (Section 2) we propose an algorithm that is based on the combination of a power-law integrator and a Page-test and for classification (Section 3) we propose pattern recognition in the spectrogram. For localisation a passive ranging technique is applied (Section 4).

2. DETECTION OF MARINE MAMMAL TRANSIENTS

For detection of marine mammal transients we have adapted an algorithm developed at the NATO Undersea Research Centre [3]. The algorithm is based on the combination of a power-law integrator and a Page-test. The power-law integrator is robust against varying signal bandwidth and the Page-test detector is an optimum detector for signals with an unknown duration. This seems to be a very useful method for detecting marine mammals with their wide variety of capricious sounds [1].

Before applying the detector a beamformer is applied to the towed array data to increase signal-to-noise ratio and to localise the mammal in bearing. The beamformer developed for the marine mammal detector is rather special, as it should deal with signals that cover the total frequency band of the CAPTAS array (10-2080 Hz). Applying a straightforward (delay and sum) beamformer to such wideband frequency band results in a frequency dependent angular resolution, which has several practical drawbacks. A proposed solution is the use of a constant beamwidth beamformer, which has (complex) frequency dependent array shading coefficients [1]. At this moment 4 beams are formed in real-time. In the consequent triplet processing the Port-Starboard ambiguity is solved [2], and finally 8 beams are made directed in the compass directions. The output of this newly designed beamformer is used as an input for the Page-test detector; see left panel of Fig.1.

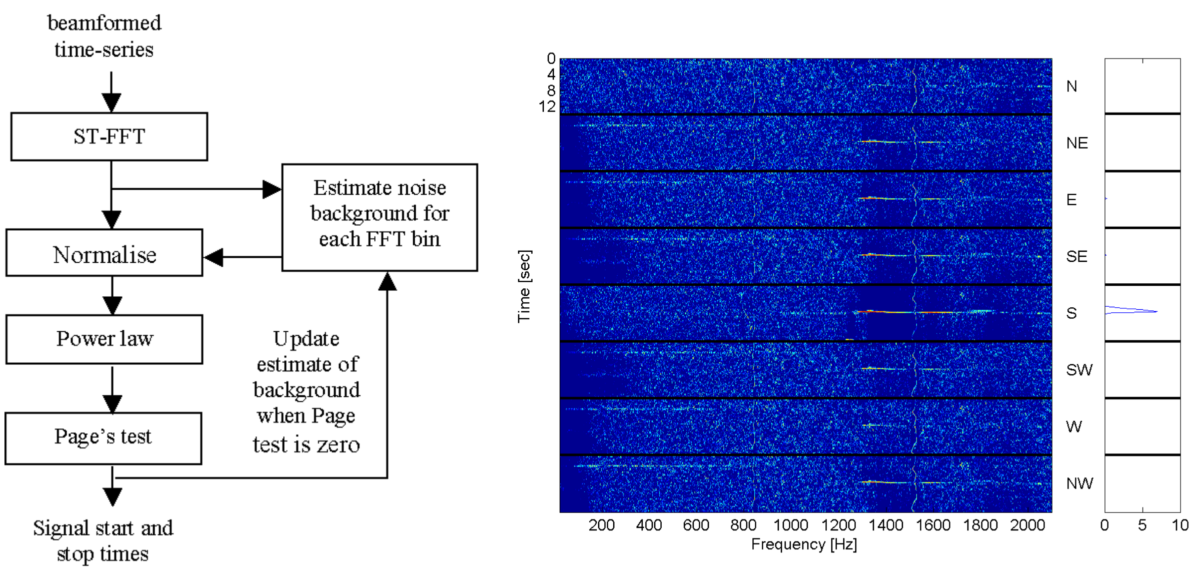


Fig. 1: On the left the schematic of the detector and on the right the detector display, which is a multi-beam LOFAR of the normalised data (left) and corresponding Page-test output (right). The blue line on the right side depicts the Page-test output and marks a short signal detection in the Southern (aft) direction.

To each of the 8 formed beams the transient detector is applied [1]. This detector is described in detail in [3] and it is successfully applied on sonar buoy data in [4]. As a first step in the detector the beam data are converted to the frequency domain by means of half overlapping short-time Fourier transforms (STFT). The integration time for the Fourier transform is always a compromise between spectral and temporal resolution. Generally a high temporal resolution (short integration time) will improve the detection of short signals like clicks (bursts) and sweeps. One of the most important steps in the detector is the estimation of the background noise. The background does not only consist of (wideband) ambient noise but also of (narrowband) shipping noise. As shown in Fig.1 the detector exploits the Page-test to isolate data that is believed to be signal free. These data are then exponentially averaged over time to estimate the background, which is subtracted from the data in the normalisation process.

The following steps are the application of the power-law integrator to the normalised spectrum. The power law integrator sums a power of the normalised frequency bins to a scalar. After a proper normalisation and in a noise only case this sum is approximately zero, while during a signal present case this sum is positive. Here several thresholds and biases start to play a role. The used Page-test has separate thresholds for the onset detection of the signal and the termination detection of the signal. Associated to these thresholds are biases in order to reduce the sensitivity.

As an example the previously described beamformer and detector are applied to recorded marine mammal vocalisations. The recordings were made using the TNO-FEL CAPTAS triplet array during an LFAS trial in 1999 near the Spanish coast of La Coruña and consist of several dolphin sweeps. This trial was conducted in co-operation with the Royal NetherLands Navy (RNLN) and Thales Underwater Systems (TUS). The output after beamforming and normalisation is shown in Fig.1. This figure is a so-called "multi-beam LOFAR". For each of the eight beams a spectrogram is shown with frequency on the horizontal axis and time on the vertical axis. A dolphin sweep is clearly visible in the Southern direction. This sweep is also weakly visible in the other directions (leakage through the sidelobes) together with some low frequency rumbles. The last column of Fig.1 shows the output of the power-law/Page-test detector. This detector performs a summation in horizontal direction over all frequency bins for each time step. Whenever this summation exceeds a certain threshold, a signal is detected. In this case, the dolphin sweeps in the southern direction are detected. After the detection of a transient, it is stored for further analysis, i.e. classification and localisation.

3. CLASSIFICATION

Classification of transients is a complicated issue. Several methods are still under study. It depends on the type of transients, which methods perform best. For marine mammal transients we propose the use of pattern recognition in the spectrogram [1]. To achieve this a processing scheme is applied as indicated in Fig.2, where different stages of processed spectrograms of harbour porpoise clicks [5] are depicted.

The *spectrogram*s are made using STFT. To these grams techniques from pattern recognition are applied. First the structures in the spectrogram have to be isolated. *Normalisation* is the most important step. The background energy in the spectrogram is often distributed rather anisotropic both in frequency and in time. This varying background should be removed before structures can be isolated through thresholding. In this study an adaptive method is applied that subtract the actually measured background. After this a *threshold* can be set. The threshold passings are clearly grouped. In the *clustering* procedure all connected points are recognised as a single cluster. This procedure is a standard Matlab® function in the image processing toolbox. All small clusters are removed; signals have either duration or bandwidth, so small clusters are often just noise.

Now that we made clusters, we are left with patterns that need to be recognised in order to classify the signal. Basically only three typical sounds are produced: clicks, moans and whistles. All of these have typical and easy recognisable patterns. Clicks are thin vertical lines. Moans are blobs and always have a harmonic structure. Whistles are snaking lines, and have (weak) harmonics. For these typical sounds "recognisers" are developed. These recognisers are built up in similar way. First clusters are reshaped by standard image processing techniques. This reshaping is necessary as for instance clicks (vertical lines) are often broken down in several fragments, which can be reconnected by filling techniques. On the other hand moans (islands) tend to be connected by narrow bridges and have to be separated. Next from the reshaped clusters *features* are determined. These features are elementary properties of the clusters like: length, height, centre of mass, standard deviation, energy content, etc. Finally these features (or combinations) are compared to standards that are representative for the patterns of the standard sounds.

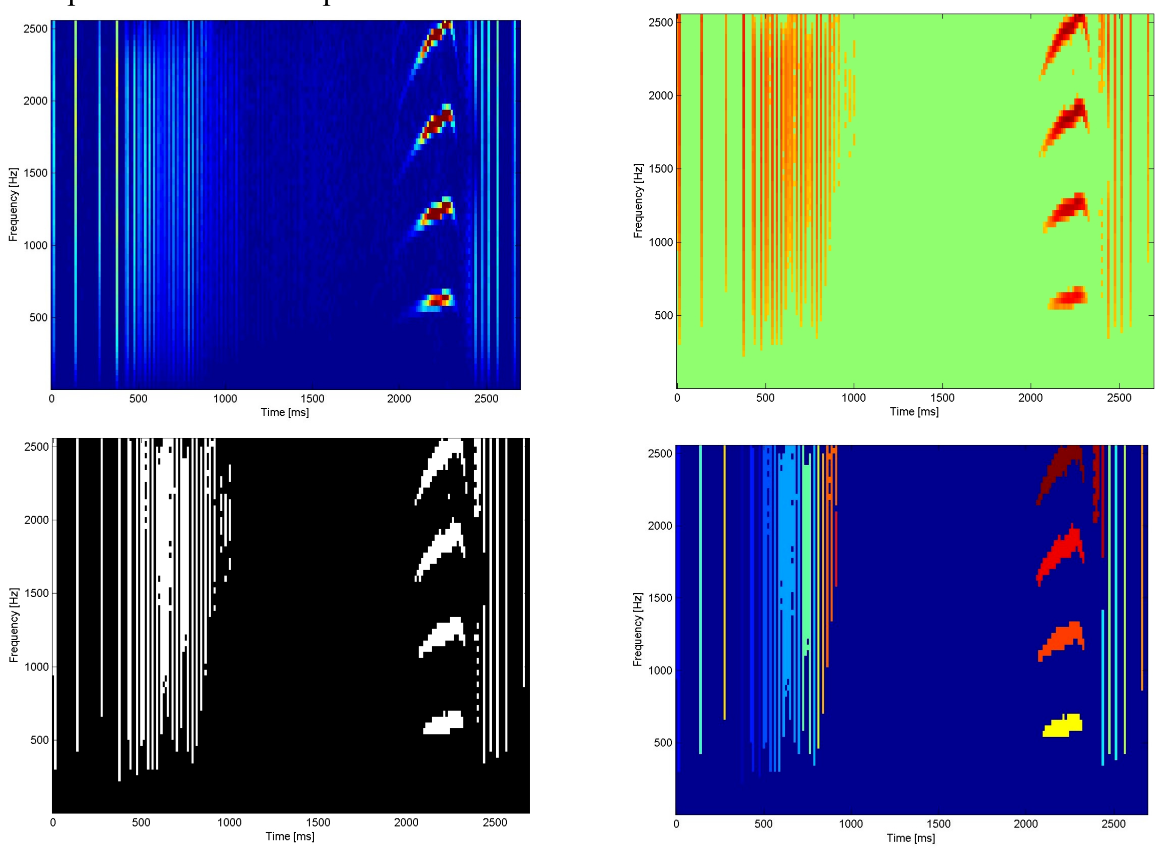
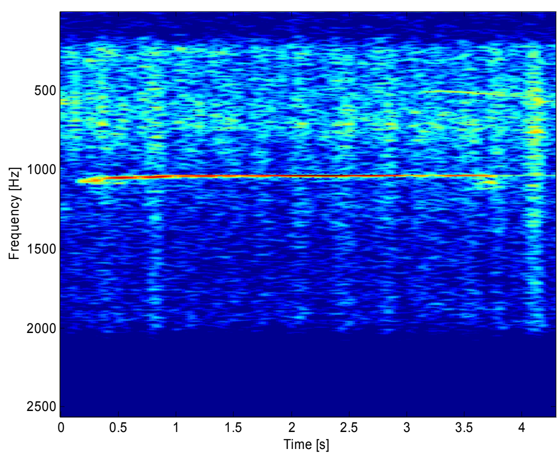


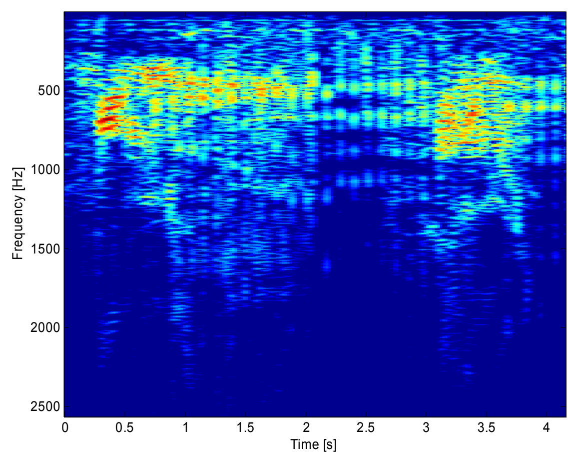
Fig.2: Processing scheme of the spectrograms to enable pattern recognition techniques. The spectrogram is made of a recording of porpoise clicks with varying repetition rate, starting slowly on the left, where clicks are clearly distinguishable, but increasing to much faster rates at 2000 ms after which in the spectrogram only the click repetition frequency is visible. a) the raw spectrogram; b) a normalised spectrogram; c) threshold passings in the normalised spectrogram; d) clustering of threshold passings colour-coded by lowest frequency.

4. LOCALISATION

The range of a marine mammal to an LFAS system mainly determines the exposure level and is therefore an essential parameter. In operational systems many different kinds of passive ranging techniques are applied (received level analysis, target motion analysis, multi-path analysis or distributed arrays techniques), though none of them has proved totally satisfactory. Passive ranging with an array is limited in performance by the Fresnel range, which separates the far field from the near field. This range limit is proportional to the aperture L of the array squared divided by the wavelength λ: $R_f = L^2 / \lambda$. The maximum range to be achieved with CAPTAS is about $R_f = 400$ m. This is considered to be on the lower edge of our needs. Still we see possibilities for passive ranging.

The originality of the method is to consider the array not as a whole but as 2 consecutive sub-arrays of equal characteristics. After estimating the relative mammal bearings θ_1 and θ_2 of each sub-array using beamforming techniques, the range is obtained by triangulation [6].





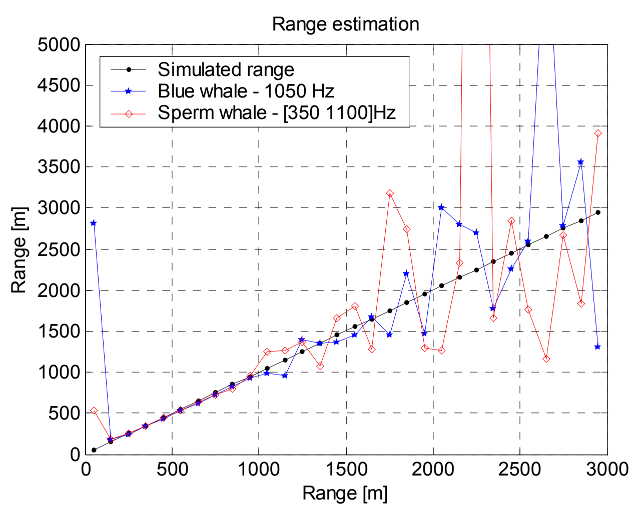


Fig.3 a)& b) are the respective spectrograms of the blue whale whistle and of the sperm whale moan used in the simulated scenarios. Fig.3 c) compares the estimated ranges for these scenarios to the simulated range.

The method is a priori simple. However, as $\theta_1 \approx \theta_2$ due to the short aperture of the array, an accurate estimate of the bearings is crucial in this process and classic beamforming on the sub-arrays seems unlikely to achieve the needed accuracy. According to the Cramer-Rao lower bound, the measurement error for an array is proportional to the 3dB beamwidth divided by the square root of the signal to noise ratio in the beam. The chosen solution was to apply a fine bearing estimation method based on an interpolation method using a cleverly adapted second order polynomial to increase the resolution [6].

For several reasons, it is difficult, if not impossible to estimate the performance of such a localisation algorithm on real data. An experiment using a submarine transmitting real mammal sound was planned during a TNO trial in 2003 near the Mediterranean coast but was unfortunately unsuccessful due to hardware failure. Regarding to these facts, scenarios were simulated with the TNO-FEL data simulator, SIMONA, in order to test this algorithm with realistic data, where a priori knowledge of the mammal position is known and for which statistics can be performed. The scenarios are as such: Real mammal sounds (from our database) are transmitted from a virtual mammal, which is 'pinging' and swimming away from the ship at a fixed pace and bearing, over 3 kilometres, in a realistic background. Two representative mammal sounds have been chosen to test the algorithm: a whale whistle (narrowband, 1050 Hz) and a moan (wideband, 300-1100 Hz). The localisation results are presented in Fig.3. The ranging of the mammals is excellent from 100 m to 1000 m (more than twice the Fresnel Range!). Moreover ranging results offer less than 5% error up to 1500 m for the wide and lower band signal (whale moan) and up to 2000 m for the narrowband signal (whale whistle).

5. CONCLUSION

LFAS arrays are designed to detect submarines rather than marine mammals. Still they are good sensors and in spite of their limited frequency range they seems quite well suited for marine mammal DCL. The described detector seems to function well, even for clicks that are partly out of band. The classifier seems at least to be able to discriminate between whales and dolphins. The localiser can range up to about 1 nautical mile.

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