Raypath Separation with High Resolution Processing

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***Abstract*—In this paper, a high resolution spatio-temporal analysis algorithm is presented and applied to separate the raypaths recorded with sensors for ocean acoustic tomography. It is a extended version of classical MUSIC, we propose it to an active large band processing dedicated for ocean acoustic tomography.We use spatial and frequency smoothing method to built projector. The experiment is done on simulated datas. Compared with classical technology using in ocean acoustic tomography, Beamforming, MUSICAL obtains more precise separation results. Besides, the results obtained by MUSICAL are with less artifacts.**

I. INTRODUCTION

In the ocean, it is possible to get images of the sound speed variation thanks to acoustic tomography. A common way to proceed is to take advantage of the multi-path properties of the wavefield [1]. Each path provides information on the variation of sound speed distribution. Recently, a tomography method has been developed using vertical arrays in emission and reception and double beamforming to separate the different paths and extract more observables. Thanks to 2D processing, the method hugely improve the conventional beamforming performances [2]. However, it is still confronted to the main beamforming drawback : the low resolution performances. As a first step of improvement, we apply a high resolution processing which combine MUSICAL algorithm [3], spatial and frequency smoothing [4]. We compare its resolution performances to those of conventional beamforming processing on simulated data.

II. HIGH RESOLUTION SPATIO-TEMPORAL ANALYSIS

High resolution methods are based on an accurate model of interference wave fields (the received signals). Then certain parameters are estimated by maximizing or minimizing a function [5]. Based on [3], we present a high resolution spatio-temporal analysis method to estimate jointly direction and arrival time, by taking into account the a priori information of the signal in MUSIC with a active antenna. In the following part, we give details.

A. Signal model

The model is built on an acoustic field composed of P raypaths on a active vertical antenna of M sensors.The temporal signal received on the m^{th} sensor is modelized as:

$$x_m(t) = \sum_{p=1}^{P} a_p e_p(t - \tau_{m,p}) + b_m(t) \qquad (1)$$

In frequency domain, (1) is written as:

$$x_m(\nu) = \sum_{p=1}^{P} a_p e_p(\nu) \exp(-j2\pi\tau_{m,p}) + b_m(\nu) \qquad (2)$$

The arrival time $\tau_{m,p}$ can be expressed as follows:

$$\tau_{m,p} = T_p + t_m(\theta_p) \qquad (3)$$

T_p represents the delay between the p^{th} source and the reference sensor, $t_m(\theta_p)$ is the delay between the reference sensor and the m^{th} sensor. $t_m(\theta_p)$ is function of θ_p, which is the direction of raypaths on the antenna.

In (2), the term $e_p(\nu)$ is deterministic. It is composed of a modulus and a phase expressing a priori information about the signal. And a_p's are considered random and decorrelated. In ocean acoustic tomography, each source corresponds to a path, $e(t)$ is the emitted signal and a_p corresponds to the complex amplitude of each path.

B. Estimation of interspectral matrix

Spatial and frequency smoothing can be introduced respectively to estimate the interspectral matrix. Making a strong smoothing either distance or frequency may introduce significant bias in the estimation of the matrix. Thus, Paulus [4]combines the two types of smoothing methods together. (K_s K_f respectively denotes the spatial and frequency smoothing factor).

From the single available observation $\underline{\mathbf{x}}$, it is possible to generate a set of $(2K_s+1)$ spatially offset recurrences $\underline{\mathbf{x}}_{k_s}$. These $2K_s+1$ recurrences may themselves frequentially be shifted to obtain $K=(2K_s+1)(2K_f+1)$recurrences $\underline{\mathbf{x}}_{k_s,k_f}$. Then we can then estimate the wideband interspectralmatrix by the following formula:

$$\hat{\mathbf{\Gamma}} = (2K_s+1)(2K_f+1)^{-1} \sum_{k_s=1}^{2K_s+1} \sum_{k_f=1}^{2K_f+1} \underline{\mathbf{x}}_{k_s,k_f} \underline{\mathbf{x}}^*_{k_s,k_f} \qquad (4)$$

C. Principle of the Algorithm

By eigendecomposition, the signal subspace is spanned by the first P eigenvectors of $\hat{\mathbf{\Gamma}}$, and its complementary, the noise subspace is spanned by the orthogonal $MF - P$ last eigenvectors. The orthogonal projection onto the noise subspace is estimated as:

$$\mathbf{\Pi}_B = \sum_{k=P+1}^{MF} \mu_{\mathbf{k}} \mu_{\mathbf{k}}^* \tag{5}$$

Finally, the HR algorithm consists in maximizing the following fuction:

$$F(\theta, T) = (\mathbf{a}(\theta, T)^* \mathbf{\Pi}_B \mathbf{a}(\theta, T))^{-1} \tag{6}$$

With: $\mathbf{a}(\theta, T)$: wide-band steering vector and is written as: $\mathbf{a}(\theta, T) = [e(\nu_1) e^{-2i\pi\nu_1 T} \mathbf{d}^+(\nu_1, \theta), \ldots, e(\nu_F) e^{-2i\pi\nu_F T} \mathbf{d}^+(\nu_F, \theta)]^+$ $\mathbf{d}(\nu_i, \theta)$ is the conventinal steering vector used in narrow band analysis [5].

III. SIMULATIONS

We illustrate the method presented previously on a set of simulated data from a software propagation parabolic equations. In this experiment, we use one source and a vertical antenna of 61 receivers. The source is fixed at 40.5 m under the ocean. The 61 receivers are regularly spaced in the water column between 30 m and 60 m. We choose the 31th sensors as the reference one. The distance between the source and the reference sensor is 2 km.

Separation results are demonstrated by Fig. 1 and Fig. 2. Globally, for each arrival raypaths, estimation values obtained by MUSICAL vary in a smaller scale and are with less artifact. Specially, shown by Fig. 3 and Fig. 4, differring to Beamforming, the first two arrival raypaths are separated totally.

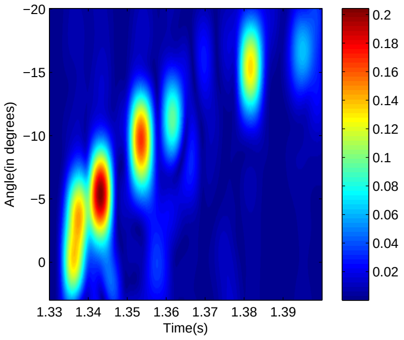

Fig. 1. Separation results with Beamforming

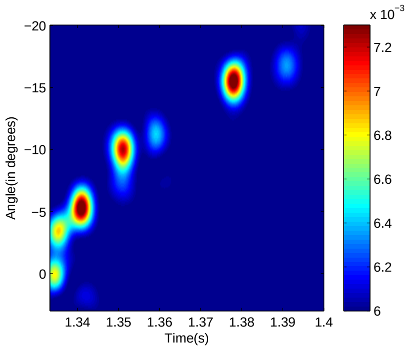

Fig. 2. Separation results with MUSICAL

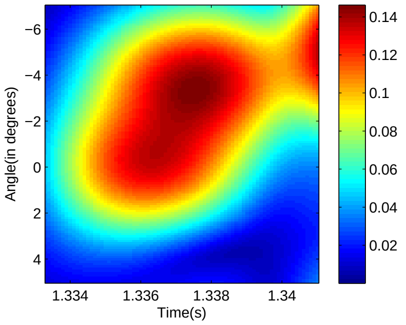

Fig. 3. The first two raypaths with Beamforming

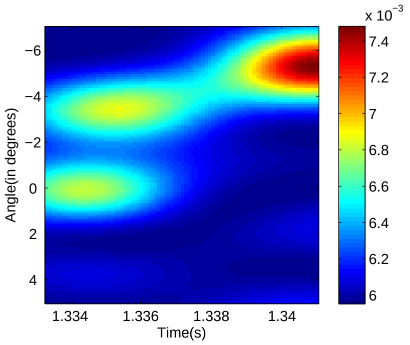

Fig. 4. The first two raypaths with MUSICAL

IV. CONCLUSION

By considering a point-array configuration, we propose an active and large band MUSIC processing applied in ocean acoustic tomography for separating raypaths. Compared with Beamforming, MUSICAl gets a better automatic detection of the number of raypaths and accurate physical position (arrival direction and time) with less noise artifacts. Next, it will be applied to double antenna with tank signal and real acoustic signal.

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