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LOCALISATION OF CORRELATED NOISE SOURCES WITH SELECTIVE LINEAR ARRAYS

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1. INTRODUCTION

The problem of localisation of acoustic sources arises in many applications, in industrial acoustics for the localisation of zones of radiated noise from a structure or in underwater acoustics.

Our interest is focused on dealing with coherent sources because they represent a frequent case in industrial applications. Most array processing techniques are not well adapted to the case of coherent sources. In these conditions, they induce errors in the localisation and in the estimation of the power of the sources. Using multiple input multiple output (MIMO) methods, these problems may be resolved for partially coherent sources. This constitutes a pre-processing step before the application of different known array treatment techniques. All these methods are applied in the frequency domain and treat the cross-spectral matrix of array sensor signals by associating it with specific reference signals. These matrices contain all the useful information about the sources. Conditionned matrices which represent the independent characteristics of each source are calculated by suppressing the contributions of all the other sources.

In this paper we present some examples of the application of these techniques to show their advantages. This approach is compared with results obtained using principal component techniques which are often proposed in other applications.

After explaining the different selective approaches, we will present results of their applications in linear array treatments of interest.

2. BASE OF THE USED ARRAY TREATMENT METHODS

2.1. Conventional method

The conventional BARTLETT method applied to linear arrays is the oldest and the simplest [1]. In its simplest form, this method consists of the direct summation of the signals from a linear array placed facing the target. Scanning can be obtained by physically rotating the array or by using appropriate time delays between the sensors. These can be expressed in the form of an "orientation vector" and a spatial spectrum. The spatial spectrum calculated with this method is directly proportional to the power of the sources.

The advantage of this localisation method is that it can be easily implemented and is not highly dependent on correlation between sources when the array resolution is adequate. However, one drawback is that in the cases where a limited number of sensors is used, the method suffers from poor resolution. Also this method introduces secondary lobes in the directivity diagram. These secondary lobes can mask the principal lobe of another weaker source. Weighting with an appropriate spatial windows can reduce the secondary lobes but also results in reduced resolution. Attractive alternatives to this classical method such as high resolution methods require less number of sensors and improve resolution at the same time.

2.2. High resolution method : MUSIC

Because of the resolution limitations of conventional methods, many high resolution methods have been studied. In the present work, we chose the MUSIC method (MUltiple SIgnal Classification) since it is the most robust [1]. The method uses an eigenvalue decomposition of the cross-spectral matrix of the array signals. By virtue of the cross spectral matrix properties (hermitian...), all the eigenvectors are orthogonal. Thus, we can decompose the expression of the cross spectral matrix into source space and noise space.

The separation of sources is possible when the cross spectral matrix of the array can be decomposed. When the sources are highly correlated the separation is impossible because the decomposition gives us only one significant eigenvalue. This is the principal disadvantage of this kind of method.

3. BASIC CONCEPTS OF PRINCIPAL RESPONSE

The method of decomposition into principal components is based on the cross-spectral matrix of the reference sources S_{XX} and the cross-spectral matrix of the array sensors. This method consists of extraction of the eigenvalues and eigenvectors of the cross-spectral matrix S_{XX} [2].

$$[S_{xx}(f)] = [U(f)][S_{x'x'}(f)][U(f)]^H$$

where

S_{XX} represents the cross spectral matrix of reference sources.

U represents the eigenvectors.

$S_{X'X'}$ represents the eigenvalue diagonal matrix.

"H" represents the conjugate transpose.

The rank of $S_{X'X'}$ gives the number of uncorrelated sources and each eigenvalue represents each independent virtual source. With this decomposition, we can construct the cross-spectral matrix correlated with the virtual sources

$$[S_{yy}(f)] = [S_{yx}(f)][U(f)][S_{x'x'}(f)]^{-1}[U(f)]^{H}[S_{xy}(f)]$$

where

S_{yy} represents the cross spectral matrix of array sensors.

S_{yx} represents the cross spectrum between reference sources and array sensors.

In the above expression, we can extract the contribution of each virtual source. Decomposition of real sources into virtual sources lacks physical meaning. In fact, there is not a relation between the real sources and the virtual sources even in a decomposition of uncorrelated sources. This represents the principal drawback of this method.

4. PRINCIPLE OF SELECTIVE METHODS

In order to explain the principle of selective methods, we will consider the simple case of the closely spaced and partially correlated sources. The formulation presented here can treat any MIMO system as combination of inputs (reference sensors) and outputs (array sensors) [3]. As mentioned above, when two sources are closely situated, the conventional method using a limited number of sensors cannot distinguish between these two sources due to limited resolution. Application of the high resolution methods presents a different problem. (The cross spectral matrix directly measured on the array will be of rank 2 except for the case of two totally correlated sources). The directivity diagram will consist of either two very close peaks or only one peak at a wrong position depending on the correlation between the sources.

Application of the selective technique requires cross spectral matrix of the reference signals. The technique consists of selecting a reference sensor associated to a source and cancelling the contributions of the other sources also represented with reference sensors.

Figure 1 presents the MIMO system of correlated sources in the case of an array of two microphones, which can be expressed as follows

$$Y_1 = H_{11} \times X_1 + H_{21} \times X_2 + b_1$$

$$Y_2 = H_{12} \times X_1 + H_{22} \times X_2 + b_2$$

where

Y_i represents the signal delivered by the sensor i.

X_i represents the reference signal of the source i.

b_i represents the noise on the sensor i.

H_{ij} represents the transfer function between the reference source i and the array sensor j.

Because of the correlation between the two sources, X_1 and X_2 do not represent the separate part of each source. To extract the independent contribution of a source it is necessary to suppress the contribution of the others by decomposing the MIMO system into two MISO (Multiple Input Single Output) systems. Figure 2 presents this decomposition when the source 1 is selected. In this case, the response of each array sensors can be expressed as :

$$Y_1 = H_{11} \times X_1 + H_{21} \times L_{12} \times X_1 + H_{21} \times X_{2.1} + b_1$$

$$Y_2 = H_{12} \times X_1 + H_{22} \times L_{12} \times X_1 + H_{22} \times X_{2.1} + b_2$$

where

H_{ij} represents the transfer function between the reference source i and the array sensor j.

L_{12} represents the transfer function between the two sources.

X_{ij} represents the signal associated with the source i without the correlated contribution of the source j.

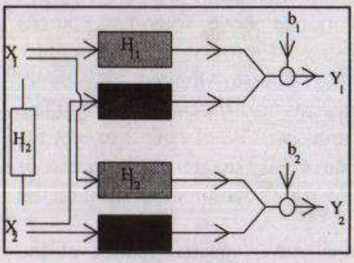

Figure 1 : A MIMO System Of Correlated Sources

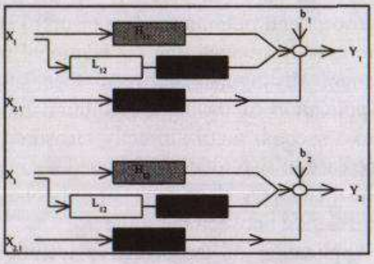

Figure 2 : Decomposition Into Two MISO Systems

Extraction of the part of source 1 uncorrelated with the source 2 follows the same procedures of decomposition of source 2.

5. EXPERIMENTAL RESULTS USING THE TWO METHODS

To compare the discussed methods, experiments were carried out using a linear array of five microphones monitoring the radiated sound field of a damped plate. Excitation of the plate is by two shakers whose driving signals are independent white noise. The reference signals are provided by two accelerometers. The correlation coefficient between these reference signals and the power spectrum of each are frequency dependent.

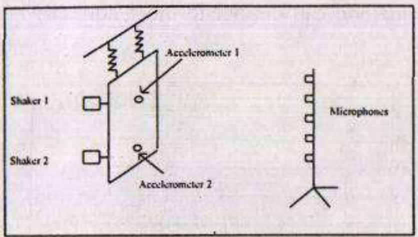

Figure 3 : Experimental setup

Figures 4a and 4b shows the angles of the sources detected by conventional BARTLETT method as functions of frequency. Distinction of the two sources is impossible due to poor resolution. In fact, one observes a curve indicating only one source erroneously detected at a position between the two real ones.

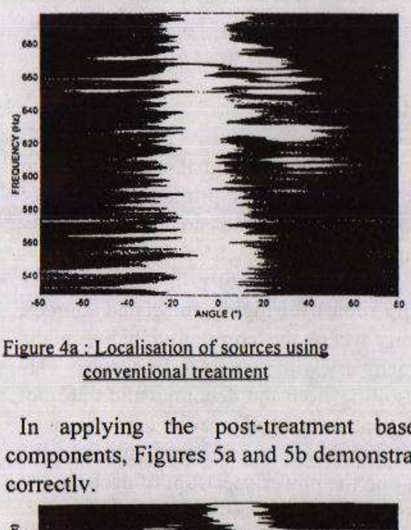

Figure 4a : Localisation of sources using conventional treatment

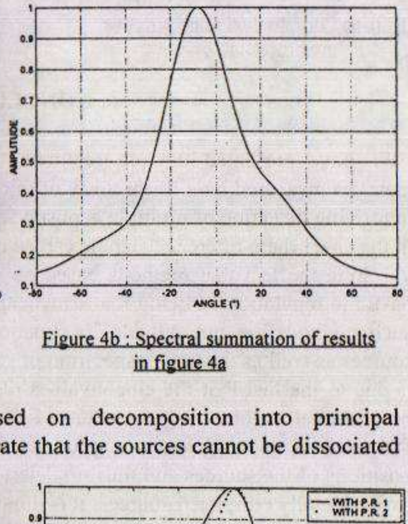

Figure 4b : Spectral summation of results in figure 4a

In applying the post-treatment based on decomposition into principal components, Figures 5a and 5b demonstrate that the sources cannot be dissociated correctly.

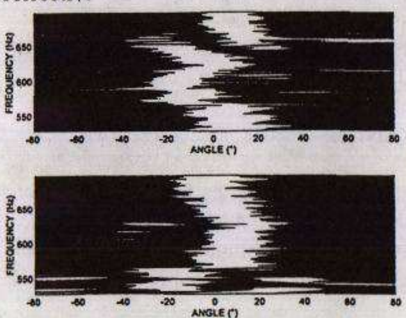

Figure 5a : Localisation using decomposition into principal response in pre-processing

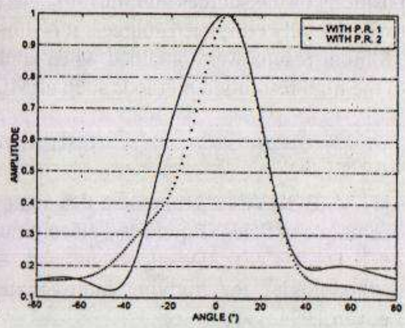

Figure 5b : Spectral summation of results in figure 5a

However, treatments using the selective method can dissociate more correctly the sources as shown in Figures 6a and 6b.

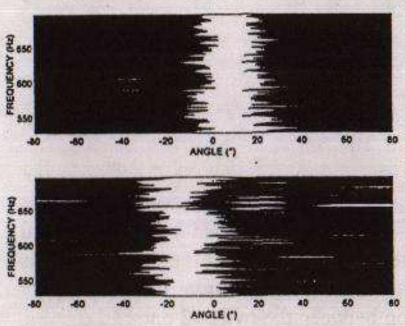

Figure 6a : Localisation using selective pre-processing

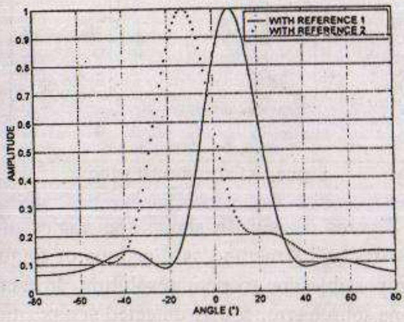

Figure 6b : Spectral summation of results in figure 6a

6. CONCLUSIONS

We have presented the pre-treatment methods of the signal cross-spectrum matrices measured by a linear array of microphones with the primary objective of improving detection of multiple acoustic sources. The methods are applicable only in the case where reference signals can be measured.

Despite the fact that methods based on decomposition into principal responses have the reputation of being mathematically robust for highly correlated sources, such methods are not reliable in situations where the correlation between the sources as well as the power spectrum of each vary with respect to frequency. This is due to the fact that the eingenvalues resulting from the decomposition are not proportional to the power spectrum of the real sources. However, application of the selective method leads to good results enabling us to detect correctly the positions of the sources and thus, to determine the power spectrum of each. In the case of totally correlated sources, it is impossible to use these approaches.

Similar results were obtained when applying the two pre-processing approaches to the high resolution methods such as MUSIC presented above.

7. REFERENCES

[1] M. BOUVET "Traitement des signaux pour les systèmes sonar.", Collection Technique et Scientifique des Télécommunications, Edition MASSON 1992.

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[3] J. S. BENDAT et A. PIERSOL, "Engineering Applications of Correlation and Spectral Analysis.", Wiley, New York 1993.