Source detection and localization using widely separated special arrays : Theoretical study and experimental results

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Introduction

In order to improve the soldier's protection and efficiency in hostile environments, the French German Research Institute of Saint Louis has developed an original acoustic array: a head equipment (HE) fitted with one or more microphones, a GPS receiver and a magnetometer. Each carrier of this HE can then be considered as a part of a large global array.

Using this kind of array involves several constraints:

- the global array has never the same shape due to the movements of the person wearing the HE,
- perturbations due to the inaccurate knowledge of the location of the constituting elements must be taken into account,
- the "acoustic shadow" generated by the HE has to be compensated.

First, we studied the behaviour of a large array with sensors spread randomly on a 10,000 square meter surface. In this case, high resolution localization methods like MUSIC [1] are applied using a spherical wave approximation. This permits the estimation of the Direction Of Arrival (DOA), as well as the estimation of the exact position of the acoustic source.

Then, using numerical simulations, we determined the consequences of an inaccurate knowledge of the microphones location. Measurements in an anechoic room confirmed the results obtained by the simulations[3].

Finally, free field measurements using a large array made up of 2 HE arrays and one classical triangular antenna took place in October 2003. Synthesized vehicule noises (generated by loudspeakers) and actual rifle shots were recorded.The results of the estimation of the localization of the sources are presented here.

Problem formulation

Consider a Head Equipment (HE) fitted with six microphones. Using these sensors together with high resolution localisation algorithms [1], it is possible to compute the Direction Of Arrival (DOA) of several acoustic sources around the array. In order to get the source/array distance estimation, it is necessary to use position detecting sensors (GPS receivers and magnetometers). Actually, these sensors detect the position and the orientation of each head equipment. A large global array can then be used to determine the source positions (Figure 1).

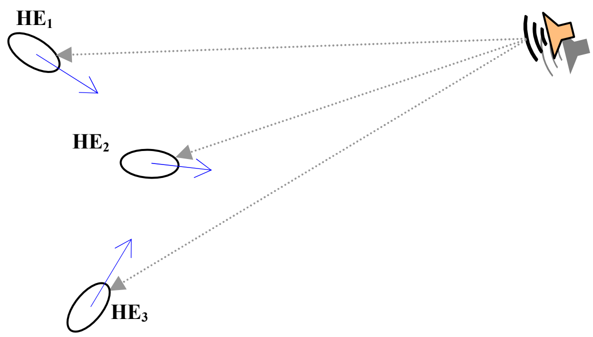

Figure 1: three HEs oriented in three different directions and constituting one large global array**.**

Due to the large dimensions of the global array, a spherical wave approximation has to be used and it is then possible to get an estimation of the position of the acoustic source. Two kinds of approach can be applied:

- separately for each HE, the DOAs of the signals are estimated. Then, the fusion of all the data gathered on each HE (DOA of each signal, position and orientation of the HE) allows to get an estimation of the position (x,y,z) of all the present sources (by triangulation). (**Method I**)
- all the microphones are used as part of one array. The data fusion is not made in a post processing phase, but before the azimut estimation. As a spherical wave approximation is used, the position of the source is immediately known with its (x,y,z) position in the space (Figure 2). (**Method II**)

A NATO experiment designed to demonstrate the feasibility of a real time monitoring of the activities of vehicles inside a limited area (4km circuit) provided to ISL the possibility to measure the efficiency of these methods. Measurements have been made with three tiangular arrays (50 cm in side), with a maximum of 50 meters space between the arrays [2]. This experiment permitted to confirm the good behaviour of the proposed methods in terms of DOA estimation when every parameter is perfectly determined (position and orientation of the arrays). However, the kind of application for which the HE is designed implies more uncertainties (errors on the knowledge of the HE position or orientation). Those uncertainties will have an influence on the performances of the estimation of the source position. This has been quantified applying model errors to simulations in which a large global array is exposed to pure sine waves.

Model errors effects

A large array constituted by M randomly arranged microphones is studied. The source is a pure sine wave and is supposed to be in the same plane as the microphones. The frequency of the signal is representative of the signals we want to localise in our application : 100 Hz. The perturbation on the position of each sensor is expressed as a percentage of the wave length of the received signal.

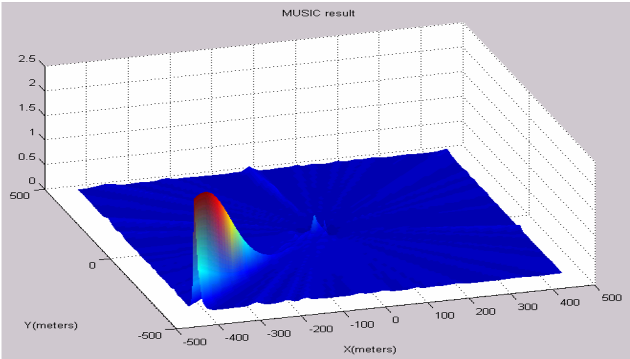

Figure 2: Result of the estimation of the source position with a $17\% \cdot \lambda$ error on the microphone position knowledge for a 9 microphones array inside a 50x50 m arera**.**
Source actual position : -400,-400 ; signal wave length : 3.4 meters

After a series of simulations, a general profile of the MUSIC algorithm behaviour has been defined. The performances for large arrays (inside a 100x100 m area) are satisfying as long as the microphone position error is smaller than 30 $\% \cdot \lambda$: more than 90% of the azimut estimations are correct and 70% of the position estimation showed less than 10% error on the actual distance to source estimation. This means that, even if the GPS receiver and/or the magnetometers supply erroneus data, good performances are achievable by large arrays constituted with several randomly placed sensors. Small scale experiments in an anechoïc room confirmed these results. Thus, 2 HE prototypes have been assembled and used in a real scale outdoor experiment in october 2003.

Real scale experiment and results

A large equilateral triangular array (25 meters side length) is made of two HEs and one 50 cm side length triangular array. Synthesized vehicle signals (helicopter, aircraft, armored vehicle) and sine waves were generated by two loud-speakers placed at a distance of 55 and 40 meters from the centre of the global array. Twenty different scenarios including three actual rifle shots have been performed. The two methods described earlier have been applied for each scenario.

In some scenarios, errors are willingly applied on microphone positions : a rotation is applied to one of the two HE, thus simulating an error in the magnetometer data. If the rotation of the HE is not taken into account in the propagation model, Method I shows large errors in the position estimation. If the Method II is used, this problem disappears, and the DOA of the source is well estimated as long as the applied rotation is smaller than 40 degrees. This confirms modelled effects of errors.

But the use of Method II creates also some problems. The small number of sub-arrays present on the field do not procure a good spatial sampling. By equiping the HE with 6 microphones, we expected the spatial undersampling to disappear. This has not been the case: the algorithm behaves as if propagation properties modifications due to the HE were model errors compared with a global array constituted by HE equiped with only one microphone (this is due to the size ratio between the global array and the HE). In order to decrease the undersampling effects, one solution consists in enlarging the subarrays. Litterature teaches us that higher order statistics allow a virtual growth of the size of an array [4] (two times its actual size). More, simulations confirmed that the undersampling effects decrease when using arrays that are two times bigger than the HE. Thus, higher order statistics seem to be a good solution in order to thwart the undersampling effects and will be introduced in the future developements of this application.

Conclusion

The kinf of array that has been studied implies a lot of constraints: the small amount of input information (inaccurate knowledge on the position of the microphones) and the lack of control on the array shape are the main obstacles for a good estimation of the source position. In this article the influence of those uncertainties has been studied. Even if high resolution methods are well known for their high sensitivity to model errors, simulations and open-field experiments led to positive results. The Simulations permit to assess the maximal accepatble positionning errors for the microphones. This value depends on the wavelength of the signal and on the size of the array. Using **method II**, experiments confirmed those results, and, furthermore, underlined the spatial undersampling problem when only a few HE are present. It also showed a poor sensitivity towards the HE rotation. The next step, will be the introduction of higher orders statistics who should help to decrease the spatial undersampling problem and increase the sensitivity towards HE rotation.

References

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