Statistical analysis of H.F. direction finding estimations

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ABSTRACT

An original, polarization-sensitive method of direction finding has been developed operating on an heterogeneous array whose antennas are different one from each other. This particular version of the MUSIC algorithm integrates an electromagnetic model of the spatial responses of the sensors. The estimation of the directions of arrival becomes more reliable with the computation of averaged pseudo-spectra and the sorting of the estimated angles. A set of criterions are applied to sort the angular estimations, picking up the actual directions of arrival and rejecting the artifacts. Experimental results are presented as a comparison between rough estimations and the corresponding sorted values.

I INTRODUCTION

An original, polarization-sensitive method of direction finding has been developed [1] operating on an heterogeneous array, the antennas of which are different one from each other. It is a particular version of the well known MUSIC algorithm, computed with an expression of the steering-vectors which integrates a reliable electromagnetic model of the spatial responses of the sensors. To achieve the estimation of the directions of arrival (D.O.A.) in an operational system, the computation of the pseudo-spectrum must be complemented with a sorting of the extracted angular values. The paper lists a set of criterions which are applied to sort the angular estimations, picking up the actual directions of arrival and rejecting the artifacts. Experimental results are presented as a comparison between rough estimations and the corresponding sorted values.

II H.F. DIRECTION FINDING OPERATING ON AN HETEROGENEOUS ARRAY

An original derivation of the MUSIC algorithm has been developed to be suitable with an heterogeneous array. For a source which direction of arrival is denoted θ_k (couple of angles in a 3-D problem), the incident steering-vector is expressed as $\left(F_1(\theta)e^{j\varphi_1(\theta_k)} \;\; \ldots \;\; F_{NC}(\theta)e^{j\varphi_{NC}(\theta_k)}\right)^T$ where NC denotes the number of sensors ,$\varphi_n(\theta_k)$ the geometrical phase of the nth sensor for the D.O.A. θ_k and $F_n(\theta_k)$ its complex spatial response. This characteristic is evaluated resorting to a deterministic model of the polarization at the exit of the ionosphere [2].

The MUSIC algorithm [3] is based on the eigen decomposition of the covariance matrix $R_{XX\,h} = E[\underline{X}_h(t)\underline{X}_h(t)^H]$, $\underline{X}_h(t)$ denoting the data vector at the output of the array. Since two polarization types (Ordinary and eXtraordinary) are expected, two sets of steering-vectors, and consequently two pseudo-spectra, are computed : the estimation of the D.O.A.'s is processed regarding the polarization as a decorrelation factor. In this context, the normalized steering-vector which is projected in the noise subspace is expressed as following :

$$b_T(\theta) = \frac{1}{\sqrt{\sum_{n=1}^{NC} \left|F_{nT}(\theta)\right|^2}} \begin{pmatrix} F_{1T}(\theta)e^{j\varphi_1(\theta)} \\ \ldots \\ F_{NCT}(\theta)e^{j\varphi_{NC}(\theta)} \end{pmatrix} \qquad (1)$$

the index T identifying the type of polarization (T=O or X).
Each pseudo-spectrum is calculated according to the following formula :

$$PSSP_T(\theta) = \frac{1}{\sum_{m=NSE+1}^{NC} \left|\underline{v}_m^T . \underline{b_T}(\theta)\right|^2} \qquad (2)$$

the set of vectors $\{\underline{v}_m\}$ defining the noise subspace.

III DESCRIPTION OF THE RECEIVING SYSTEM

A 8 coherent channel receiving system has been developed by the IETR. laboratory near Rennes. This system includes
- 8 active loop antennas with a 1.3 meter diameter and a low noise pre-amplifier
- 8 identical coherent receivers, the design of which resorts to 2 frequency mixers
- a synchronous 8 inputs analog to digital converting card with a resolution of 12 bits and a sampling frequency being adjustable up to 120 kHz.

The array is circular with a radius of 25m. The antennas are uniformly distributed on the circle but they are submitted to a rotation of 30 degrees along a vertical axis between two successive positions, so that the array becomes heterogeneous (Fig. 1).

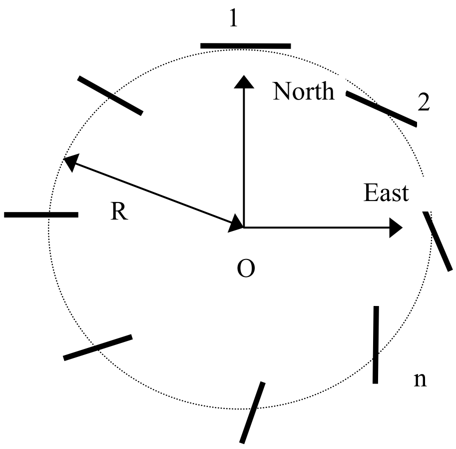


Fig 1. Heterogeneous circular array

IV IMPROVING AND SORTING THE ANGULAR ESTIMATIONS

In order to provide a reliable estimation of the D.O.A., a large size file of acquisitions is processed (typically 120000 samples at a rate of 40 ksamples/s) and then is arranged to achieve an effective averaging of the pseudo-spectra and sorting of the angular estimations The acquisition is divided in 20 consecutive parts ; each part is divided in 5 series with a 50% overlapping. For each part, a pseudo-spectrum for each polarization is computed by averaging the angular functions provided by the 5 time series. In an ideal case, if each part of data give a valid pseudo-spectrum for each polarization, statistics are available for the D.O.A. estimation (mean and standard deviation for elevation and azimuth) upon a set of 20 data.
However, a first set of criterions [4] are used to validate the pseudo-spectra.

For each time series:
- threshold on the major eigen value of the covariance matrix to ensure that the level of signal is sufficient regarding the quantum of analog to digital conversion
- threshold on the major to the minor eigenvalues to protect from a poor signal to noise ratio

For each part of the acquisition :
For each expected polarization, the tests are :
- verifying that the maximum peak (reference) of the averaged pseudo-spectrum is clearly higher that the mean value
- filtering the local maxima with an azimuth separated from the reference azimuth by more than a fixed threshold

Considering both polarization, an additional original criterion is based on the computation of two pseudo-spectra (O and X) : if several signals with different polarizations are detected, the corresponding estimated azimuths must be contained in a limited interval considering a single transmitter.

- verifying that the absolute maxima for each polarization are in a convenient ratio (if not, rejecting the smallest pseudo-spectrum)
- verifying that the azimuths of the two references are separated by less than the fixed threshold

If at least one averaged pseudo-spectrum (O or X or both) passed these tests, it yields one angular estimation.

The set of angular estimations are then sorted according to the following points :
- identification of the most occurring number of paths and selection of the corresponding angular estimations
- in this context, rejection of the estimations which values appear too far from the mean

Applying these tests to the rough estimations contribute to reduce the dispersion of the results. The statistics (mean and standard deviation) of the angles of arrival are then computed with the estimates that pass through the whole set of tests.

V Experimental results

V-1 Pseudo spectra

Direction finding measurements have been processed with the above described receiving system. A large number of acquisitions has been collected, involving several broadcast transmitters in the H.F. range (3-30 MHz) more than 1000km far from the receiving site. The particular structure of the heterogeneous array enables the computation of two pseudo spectra (O and X) from which are realised the angular estimations.
The figure 2 represents an example of a pair of pseudo spectra. The corresponding transmitter is located in Morocco (carrier frequency 9.575 MHz) and the geographical azimuth is equal to 178°. Two paths with opposite polarizations are detected and appear with estimated values of the azimuth that are close to the reference.

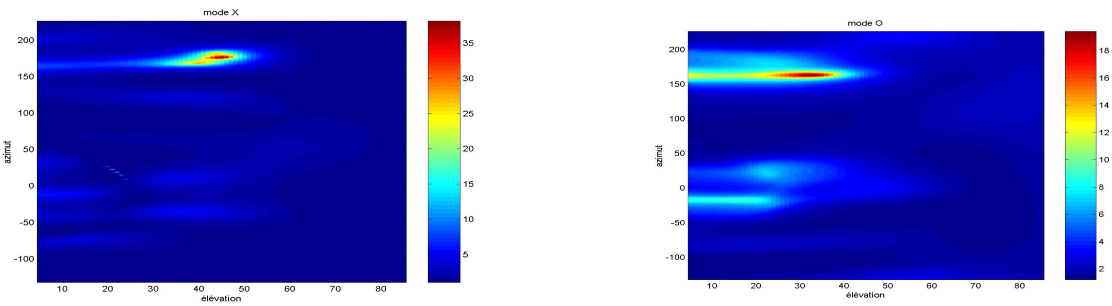


Fig 2. Examples of pseudo-spectra

V-2 : Post-processing

The benefit of the statistical analysis is underlined by comparing for a large scale time series the rough angular estimations (plotted in blue) and those which where validated through the set of tests (plotted in red). Each estimations is based on the computation of two averaged pseudo-spectrums.
An example is illustrated on figure 3 where the estimated azimuths are plotted as a function of time (or the number of file) during the receiving sequence ; the corresponding transmitter is located in Rordhorf (Germany), the carrier frequency being equal to 7.265 MHz and the expected azimuth equal to 90°.

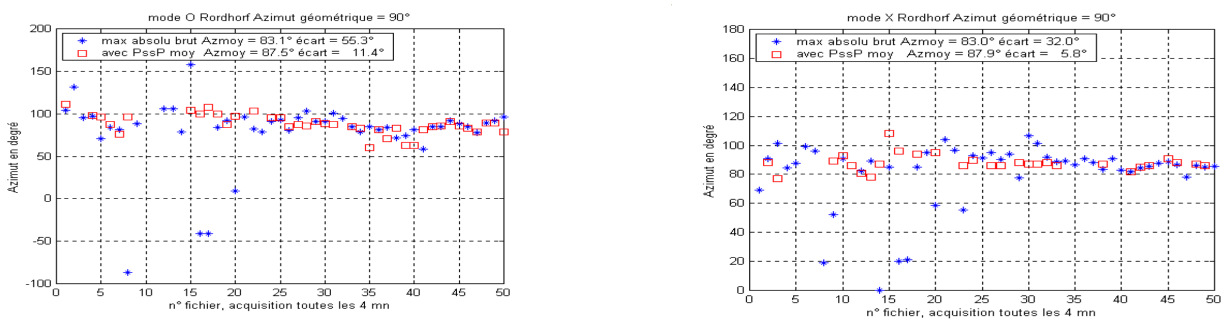
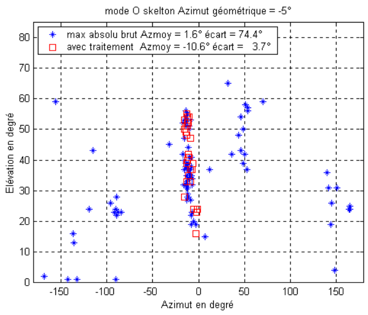


Fig 3. Improvement of the angular estimations resorting to the statistical analysis

The standard deviation of the angular estimation (azimuth) is significantly reduced by the post-processing (55.3° versus 11.4° for the O mode and 32° versus 5.8° for the X mode).

An other example (Fig 4.) concerns the received signals with a carrier frequency equal to 12.095 MHz. The transmitter is located in Skelton (U.K.) and the geographical azimuth is equal to –5°. The chosen representation gives jointly the elevation and the azimuth of the estimated D.O.A., with (red plot) or without (blue plot) the post processing.



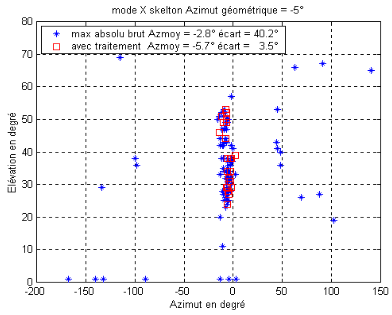


Fig 4. Improvement of the angular estimations resorting to the statistical analysis

The dispersion of the estimations is clearly reduced by the post processing. The values of means and standard deviations (azimuth) with or without post processing are gathered in the following table :

	Azm Xmode	σ_{Az} Xmode	Azm Omode	σ_{Az} Omode
without post processing	-2.8°	40.2°	1.6°	74.4°
with post processing	-5.7°	3.5°	-10.6°	3.7°

Table 1 : means and standard deviations of the angular estimations

VI CONCLUSION

This work improves the robustness of the angular estimation yielded by a high resolution method of direction finding. A set of tests give the mean to make the computation of pseudo spectra more reliable, to reject the poor estimated values and consequently to reduce the mean square error of the angular estimation. This technique is now implemented in an operational system and is currently validated for a large choice of experiments. The benefit of the post processing has been underlined after numerous runs on real acquisitions.

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