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Robust auto-focusing wideband DOA estimation

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Abstract

Within the last decade there has been a growing interest in developing techniques for the estimation of the direction of arrival (DOA) of wavefronts carrying wideband signals in order to locate the emitting sources. The coherent signal-subspace method (CSM) is one of the most largely adopted iterative technique based upon the concept of signal-subspace, due to its ability in handling coherent sources, while showing very good detection and resolution thresholds, low bias and high accuracy.

Central to CSM is the use of the so-called focusing matrices, whose characteristics strongly influence its overall performance. In the literature, several focusing matrices have been proposed and the most effective of them often require initial estimation of the DOAs, which could be a drawback for the overall estimation procedure. Furthermore classical focusing design techniques do not take into account the fact that at each iteration of the algorithm estimated DOAs may differ from the actual ones on which the manifold should be focused.

In this paper we propose a novel focusing matrices design technique aimed at counteracting some of the main disadvantages of other classical focusing matrices. It is shown that the classes of Rotational Signal Subspace and Signal Subspace Transformation focusing matrices leave room for further optimization of the available degrees of freedom, that are exploited here to create a CSM robust against DOA estimation errors. For this reason, the proposed method is referred to as *robust coherent signal-subspace method* (R-CSM). Thanks to the peculiarities of these novel focusing matrices, the initial preprocessing stage of the classical CSM is no longer required. Furthermore, the convergence speed is improved, because at each iteration the degrees of freedom are used to concentrate the focusing closer and closer about the estimated DOAs.

Keywords: Array processing; Wideband sources; DOA estimation; Coherent signal-subspace; Focusing matrices; Robust auto-focusing

1. Introduction

Processing of wideband signals collected by arrays of sensors arises in many application domains such as radar, sonar, seismology and

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communications. Within the last decade there has been a growing interest in developing techniques for the estimation of the direction of arrival (DOA) of wavefronts carrying wideband signals in order to locate the emitting sources.

Two well-known families of approaches for estimating the DOA of signals are the methods based upon maximum likelihood and those based upon the concept of signal-subspace. The latter, although not optimal, is attractive since it is computationally lighter than the former and yields to extremely accurate estimates without having the problem of converging toward local maxima [1].

One of the first approaches proposed in literature to cope with the wideband problem exploiting the concept of signal-subspace is referred to as *incoherent signal-subspace method* (ISM) [2,3]. Basically the method decomposes the received signal into narrowband portions and at each frequency bin an individual processing is performed in order to estimate the DOA of the impinging wavefronts. Then the partial results are combined to provide the final estimate. The main drawback of this procedure is its unability to resolve coherent sources [4] which, in turn, are extremely likely to appear in all those propagation conditions wherein several delayed replica of a certain signal arrives at the array through different paths (multipath propagation).

Lately, Wang and Kaveh [4] propose a technique referred to as *coherent signal-subspace method* (CSM) with the purpose of improving ISM performance by also handling wideband coherent sources. Unlike the conventional spatial smoothing method [5], the CSM performs a sort of frequency smoothing with the aim of circumventing the coherence problem without reducing the effective array aperture. The main difficulty in developing coherent signal-subspace processing is due to the fact that the signal-subspace changes with frequency. The basic idea to overcome this problem is to apply a linear transformation to the array power spectral density (PSD) matrix estimated at each frequency bin, with the purpose of removing the frequency dependence of the transformed signal-subspace and creating a single universal matrix having desired algebraic properties that can be exploited by subsequent processing stages to estimate the number of impinging wavefronts as well as their DOA. The linear transformation is performed by means of the so-called *focusing matrices*, whose name recalls the fact that they are designed to focus the signal subspace at each frequency bin into a certain reference frequency. Unfortunately, the focusing procedure often would require the knowledge of the exact DOAs, which are the final objective of the whole estimation procedure. Therefore, the DOAs are first roughly estimated and then focusing is applied onto an approximate signal-subspace. In this way a set of better estimates can be obtained and the procedure can be iteratively performed until stable DOA estimates are available. Among the advantages of CSM there are the capability of handling coherent sources, superior detection and resolution thresholds and improved bias and accuracy, compared to ISM. Detection and estimation performance of CSM are studied in [6].

The pioneering work of Wang and Kaveh [4] was the first presenting the use of focusing matrices for wideband DOA estimation. Subsequently, many authors proposed improvements to the approach by investigating the characteristics of desirable focusing transformations and by suggesting better ways to design focusing matrices. Among the others, remarkable performance is achieved with the use of *rotational signal-subspace* (RSS) focusing matrices proposed by Hung and Kaveh [7], lately extended by Doron and Weiss [1] to the more general class of *signal-subspace transformation* (SST) matrices. In [8] Hung and Mao proposed a class of robust focusing matrices called *unitary constrained array manifold focusing* (UCAM), which reduces the sensitivity of RSS-CSM to variations of initial focusing angles.

All the paper cited above share the same characteristic of requiring initial DOA estimates, which could be a drawback. Indeed the whole estimation procedure necessitates of a pre-processing stage, which calls for additional computational burden, while providing only low-accuracy DOA estimates. Unfortunately, the lower the initial accuracy, the longer the iterative DOA estimation procedure must be performed in order to get the final, possibly accurate, result.