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DIRECTION OF ARRIVAL ESTIMATION WITH SENSOR ARRAYS

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Abstract

With recent increase of hardware capabilities, the application of sensor arrays in the Direction-Of-Arrival estimation is gaining more and more popularity. The behaviour of the array is the complex function of the geometry, sensor characteristic, signal and noise properties and other different factors. Before building the array it is essential to simulate its performance in different conditions with different algorithms.

Most of the time the simulations are performed using custom ad-hoc created code. This code is error prone and difficult to maintain. Our goal was to create a reusable and extensible library that would provide the components used in the simulation process. In this paper we present the initial version of the library along with several illustrative examples.

Keywords: Array signal processing; Signal processing; Simulation software, Direction of arrival estimation; Parameter estimation

1. INTRODUCTION

Development of new technologies carries new possibilities for the signal processing. Array signal processing is very important in radio-communication. It is concerned with the extraction of information from signals which are collected using an array of sensors. Sensor arrays can improve the capacity of localising the sources of energy and help mitigate the effects of noise and interference. One of the important areas of sensor array processing is the Direction-Of-Arrival (DOA) estimation [1, 2, 3].

DOA estimation is a computationally intensive task that relies heavily on linear algebra operations. Recent advances in the FPGA solutions allowed implementing some of the algorithms entirely in hardware with relatively low cost. This might have been a turning point in the history of array processing.

2. SIMULATION LIBRARY

2.1. OVERALL DESIGN

In order to simplify the process of simulating different types of sensor arrays and DOA algorithms, an extensible proof-of-concept C++ library has been created at Institute of Radioelectronics, Warsaw University of Technology. The main focus was on providing a generic, rich and intuitive scientific computation library.

The library can utilise either the real measurement data or data from the Monte-Carlo simulations (i.e. using the data from the multivariate Gaussian distribution). Different variants of data generation can be added, as long as they adhere to a simple interface concept. Additional preprocessing of the data is possible (i.e. decorrelation via spatial smoothing [4]).

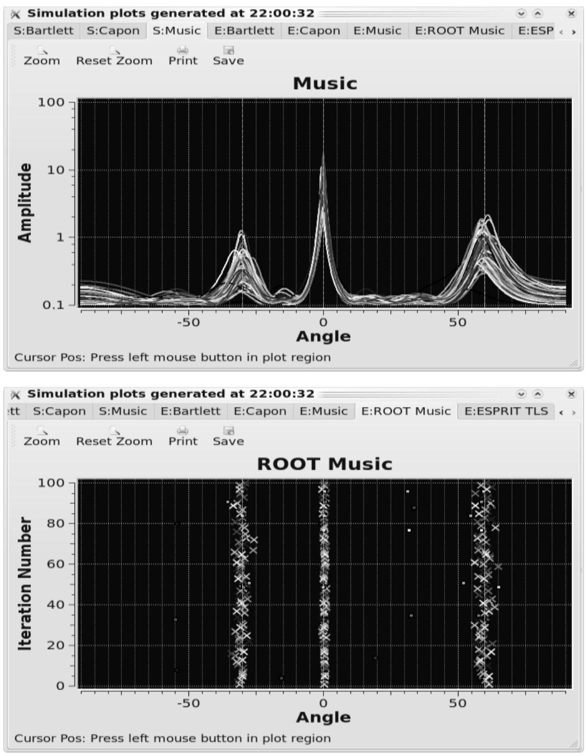

Fig. 1. Screenshot from the sample educational application created with the prototype library.

The library uses BLAS and LAPACK routines for the linear algebra operations (major processor vendors provide heavily optimized versions of these libraries) and provides a straightforward API.

A simplified diagram of the library concepts and elements is presented at Figure 2. These elementary blocks are used together when designing the simulation process. New concepts and implementations can be added in order to extend the initial functionality provided.

As a sample application it has been used to compare the performance of several DOA estimation algorithms in different scenarios (sample at Fig. 1).

2.2. Array Geometry

Uniform Linear Arrays are notably prevalent in many different applications. It is because of their simplicity (both the construction and the calculations), amount of the prior research and the abundance of available algorithms (exploiting the properties of the ULA arrays). For this reason, for the time being, the simulations were concerned with the ULA arrays. The sensors were assumed to be uniform and omnidirectional.

The library allows to define different types of arrays and sensors (for example the arbitrary geometry array with mutual couplings among the elements which can have significant impact on the antenna directivity and in turn on the behaviour of the whole array).

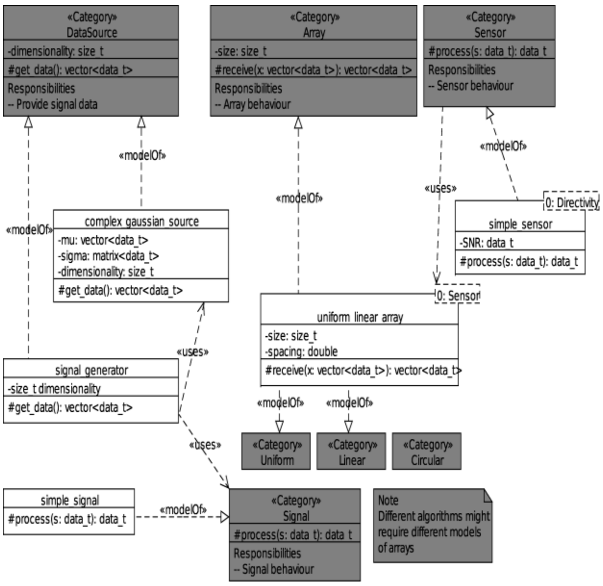

Fig. 2. Simplified diagram of the concepts used in the prototype library and the implementation examples.

2.3. Supported Algorithms

Currently the library supports the classical beamforming algorithms (Bartlett and Capon [5]) and several superresolution methods (different variants of MUSIC [6] and ESPRIT [7]) for narrowband signals. Before providing more algorithms it is necessary for us to find a suitable optimisation library (in terms offered algorithms, interface and license).

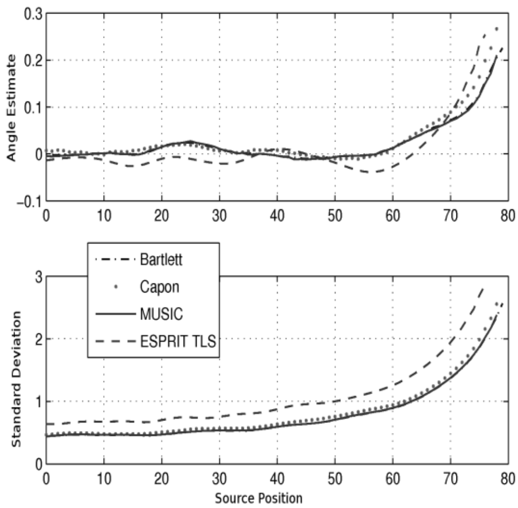

Fig. 3. Illustration of the influence of the source angle-of-arrival on the parameters of the estimates. Simulations were performed for L=10 element array with N=50 signal samples, SNR=20dB

Choosing an appropriate algorithm for the given application is far from trivial. Simple algorithms might not work in harsh conditions, while complex algorithms may be inadequate because of the required computing power. Certain algorithms (e.g. ROOT MUSIC, ESPRIT) are able to produce directly the needed estimates, while others need to search the parameter space for the solution. In some conditions the algorithm might not be able to produce the correct estimates (i.e. by producing fewer estimates than expected).

2.4. Simplifying Assumptions

As for today the library is a proof-of-concept created in order to test the applicability of the component package for speeding up the analysis process. Several simplifying assumptions prevailing in numerous publications [1, 2, 3] have been adopted (the most important is assumption of narrowband signals). Many of these simplifications are completely orthogonal to the design of the library, but it is necessary to verify whether current generic model can support more complex cases.

3. Simulation Examples

In order to assess the usefulness of the library several simulations of the DOA scenarios had been implemented. Below we present results from a few chosen cases.

The accuracy of the estimates depends on many factors, including the signal's angle-of-arrival. The best results are obtained when the source is at the broadside

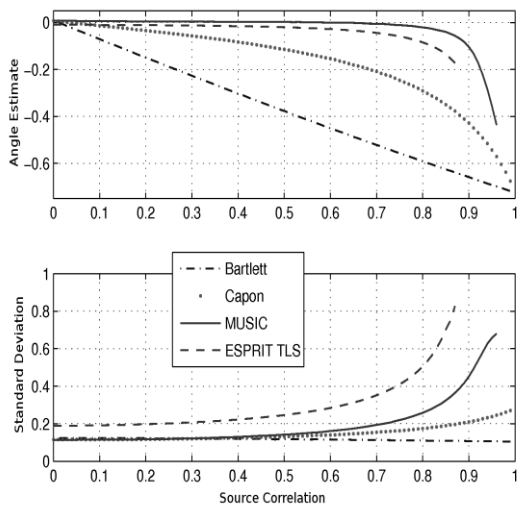

Fig. 4. Illustration of the influence of the source correlation for the parameters of estimates. Simulations were performed for L=12 element array with N=500 signal samples, SNR=0dB and sources located at 0° and 30°.

of the array. The farther the sources are from the broadside, the greater bias is introduced (Fig. 3).

In the presence of multiple sources, the source separation and source correlation play the crucial role in DOA estimation. “Superresolution” methods continue to provide the estimates even for the closely placed sources. However they are more prone to source correlation (which is a common phenomenon in real-life applications, caused for example by reflections). From (Fig. 4) it visible that the classical algorithms tend to work and provide biased (but consistent) estimates even for high values of correlation between the sources.

From the obtained results it is clearly visible that the choice of a particular algorithm depends heavily on the application and available computing power (for certain situations complex methods may be appropriate, while for other Bartlett solution is sufficient). The library aims to simplify the effort needed to make the choice.

4. CONCLUSIONS

Sensor array processing is a complex task involving many factors. Even the relatively simple examples that were presented show the necessity of careful design process.

The initial results from the generic sensor array processing library development are encouraging. It may be necessary to introduce some interface changes in order to accommodate more complex scenarios (i.e. wideband signals). Furthermore, a deeper investigation of the numerical stability of the implementation is needed in order to assess the errors and provide a robust solution.

The generic library can be used for simplifying the design process – by providing a common set of components and standards for creating the simulations. In addition to that it can serve the educational purposes (by providing self-explanatory working code snippets to support the course material for the students, by allowing creation of simple demonstration applications to facilitate the learning process).

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