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Surrogate Data Generation Technology Using the SSA Method for Enhancing the Effectiveness of Signal Spectral Analysis

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Abstract—The problem of enhancing the effectiveness of spectral analysis of signals observed against the background of noise has been considered by using the Root-MUSIC method and the surrogate data technology that is free from surrogate noise. The surrogate data was obtained by using the singular spectrum analysis method (SSA). The application of this technology was shown to be effective in the range of both small and large signal-to-noise ratios when the frequencies of signal components are a multiple of the observation sampling frequency.

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INTRODUCTION

There are many studies dealing with the spectral signal analysis that includes solving problems of determining the number of signal harmonic components and estimating their parameters from an observation in the presence of additive white Gaussian noise. As noted in these studies, the effectiveness of spectral analysis largely depends on the signal-to-noise ratio (SNR), the number of observations and the selected method of analysis [1].

The so-called eigenstructure methods (ES) occupying a special place among the state-of-the-art methods of spectral analysis are often applied in processing of spatial-temporal signals [1–3]. These methods are based on using the information contained in eigenvectors (EVe) and eigenvalues (EVa) of correlation matrix (CM) of observations.

For reducing the noise impact on the estimate of observation CM in antenna arrays (AA) the multiple registration of field from signal sources and subsequent processing of the ensemble of observations are used, if possible, for improving the CM estimate. If signal components are correlated, they are decorrelated by smoothing the CM estimates [1] obtained from incomplete data sampling covering a part of AA elements.

However, in practice, there are not infrequent situations where the signal power is less than the noise power, and it is not feasible to obtain a large ensemble of observations [1–4]. In addition in this case a single observation is available for processing, and its length is insufficient (small sampling) for employing asymptotic properties of its distribution statistics.

It should be noted that decorrelation of observations (signals) using the spatial smoothing of CM leads to inadmissible reduction of the spectral analysis resolution [1]. For such situations the effectiveness of spectral analysis by classical methods becomes insufficient.

The problem of small samplings and low SNR values can be partially solved by using the computer-oriented approach in statistics [5] that seems promising, but has not yet found a wide practical application. In nonclassical statistics and nonlinear dynamics this approach makes it possible to develop methods for generating the so-called pseudo-samples using the strategies of data randomization. The best known pseudo-sample generation methods include permutation, bootstrap and the jack-knife technique [5], and also randomization of sampling by white noise dithering [6].

The development of methods for generating an ensemble of pseudo-samples was proposed in paper [7]. In nonlinear analysis of time series these methods are called the technology of obtaining surrogate data.