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Signal Processing Correction in Spectral Analysis Using the Surrogate Autocovariance Observation Functions Obtained by the ATS-Algorithm

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Abstract—The problem of processing correction of signals observed against the background of noise has been considered in relation to their spectral analysis by the Root-MUSIC method using the technology of surrogate autocovariance functions (ACF) of observation. The results of simulation modeling are presented dealing with the correction of observation processing by means of the phase randomization of spectral components of observation ACF using the ATS-algorithm for generating the observation surrogate ACF. It has been shown that in generating surrogate data from the observation ACF, ATS-algorithm ensures the highest efficiency at small signal-to-noise ratios.

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INTRODUCTION

A number of practical situations typical for radiolocation, radio communication, and other applications involve the need of implementing the signal processing with required accuracy (efficiency) at a low value of the signal-to-noise ratio (SNR) and/or small sample size of observations. In such cases the efficiency of signal processing can be enhanced by complementing the classical asymptotic statistical methods with computer-oriented ones [1–4]. These technologies combined by the common term “resampling” make it possible to develop the methods for generating the so-called “pseudo-samples” in case the repeated attempts of receiving true observations (or increasing the sample size) are not feasible.

Resampling methods combine three different approaches with different, but similar in essence, algorithms: permutation, bootstrap, and jack-knife method [1–4]. There is also known a variant of bootstrap, where small independent uniformly distributed noises are added to the initial data [2, 5, 6].

The development of resampling methods was proposed by Theiler et al. in 1992 [7] for the purpose of detecting nonlinearities in time series. In nonlinear analysis of time series these methods are called surrogate data technology [7, 8].

Among the algorithms of surrogate data formation two groups can be singled out: those preserving the statistical properties of observations and the algorithms preserving the properties of their attractors.

The first group includes the algorithm with random shuffling of the input data array (random shuffle algorithm), the Fourier transform algorithm, known also as the algorithm with randomization of the observation Fourier-spectrum phase (random phase (RP) algorithm), and the algorithm with signal amplitude adjustment after the Fourier transform (amplitude adjusted Fourier transform algorithm) [7, 8].

The second group includes the ATS (attractor trajectory surrogates) algorithm and pseudo-periodic surrogate formation algorithm [8]. These algorithms preserve the statistical and dynamic properties of input signals, but require a much larger number of operations for obtaining surrogate data.

There are many papers dealing with the spectral analysis of signals [9, 10], where it is noted that the analysis efficiency materially depends on the SNR. These inferences are also valid for the eigenstructure (ES) methods of spectral analysis (Root-Music and others) [5, 6, 11, 12]. That is why the search for new approaches to solving the problems of spectral analysis at small values of the SNR is an important task.

One of such approaches is based on the correction of classical methods of spectral analysis (enhancing the estimation accuracy of signal spectral components and their resolution).

The efficiency of processing correction of signals observed against the background of noise is shown in paper [13] for the case of signal incoherent spectral analysis by the Root-Music method using the surrogate