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Enhancing the Efficiency of Spectral Analysis of Signals by the Root-MUSIC Method Using Surrogate Data

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Abstract—A problem of enhancing the efficiency of spectral analysis of signals observed against the background of noise by using the Root-MUSIC method and the technology of surrogate data obtained by the randomization of phases of spectral components of observations has been considered. The results of spectral analysis simulation are presented. The application of this technology was shown to be effective at small and large values of the signal-to-noise ratio when the frequencies of signal components are a multiple of the observation sampling frequency.

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INTRODUCTION

The fundamental complexity of practical realization of information measuring radio systems (RS) is explained by the presence of interferences during observation that reduces the efficiency of signal processing. For taking into account the interferences during observations the statistical RS theory uses classical asymptotic methods of the statistical decision theory. The philosophy of this theory is common for many applications related to signal processing.

The fundamental aspect is the fact that in practical applications it is often not possible to satisfy the conditions of applicability of classical statistical methods due to the insufficient sample (ensemble) size of observations and (or) low values of the signal-to-noise ratio (SNR) that is equivalent to the reduction of the effective sample size.

The last decade the research workers pay attention to the possibility of enhancing the efficiency of signal processing by complementing the classical asymptotic statistical methods with computer-oriented ones, some of which make it possible to increase the effective sample size by forming a pseudo-ensemble via the generation of resamplings from the initial data array. Examples of such methods may be the bootstrap, permutation of samples, randomization of observations by addition of small independent identically distributed noises (linear randomization) [1–7].

The basic idea of bootstrap-methods is reduced to the multiple random selections from the observed data of their elements with subsequent return into the initial data array.

The development of resampling generation methods was continued by Theiler et al. in 1992 [8] for the purpose of detection of nonlinearity in time series. In nonlinear analysis of time series these methods are called surrogate data technology [8, 9].

Two groups can be separated among the algorithms of surrogate data formation: those maintaining the statistical properties of observations and maintaining the properties of their attractors.

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 algorithm), which generalizes the linear randomization [5–7], and the algorithm with signal amplitude adjustment after the Fourier transform (amplitude adjusted Fourier transform algorithm) [8, 9] can be referred to the first group.

The second group of algorithms makes use of the observation images in pseudo-phase space. They include, in particular, the attractor trajectory surrogates (ATS) algorithm and the pseudo-periodic surrogate formation algorithm [9]. These algorithms preserve the statistical and dynamic properties of observations, but require a much larger number of transformations for obtaining surrogate data.

In [10–12] the ATS algorithm and its modifications were used for empirical estimation of the likelihood ratio [10], reduction of the noise impact during the observation of chaotic carrier during the binary message