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Adaptive Variant of the Surrogate Data Technology for Enhancing the Effectiveness of Signal Spectral Analysis Using Eigenstructure Methods

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Abstract—The problem of enhancing the effectiveness of spectral analysis of signals observed against the background of noise by the Root-MUSIC method has been considered using the surrogate data technology implemented by adapting the algorithm of phase randomization of the Fourier transform samples of the initial data in relation to the signal-to-noise ratio (SNR). The proposed variant of the surrogate data technology was shown to be effective at low values of SNR and a small number of samples. At large values of SNR an additive variant of the surrogate data technology actually does not cause an emergence of surrogate interference typical for nonadaptive variant. The proposed variant of the technology can be applied in combination with other methods of spectral analysis.

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Among the modern methods of spectral analysis the eigenstructure (ES) methods (Pisarenko, MUSIC, Root-MUSIC, ESPRIT, Min-Norm and others) using eigenvectors (EVe) and eigenvalues (EVa) of correlation (covariance) matrix of observations occupy a special place. These methods are also known as EVe subspace-based methods [1].

The problem of search for EVa and EVe of the observation correlation matrix (CM) can be also solved by using the Karhunen–Loeve expansion, principal component analysis (PCA), independent component analysis (ICA), nonlinear principal component analysis, factor analysis and the canonical analysis that have received wide acceptance in processing of signals and images [1–4].

EVa and EVe of input data CM, besides the spectral analysis methods, find application during the analysis of the convergence rate of signal processing algorithms in adaptive antenna arrays (AAA), during the optimization of weight coefficients of rejection filter of moving target selection systems, and during the determination of resultant directivity pattern of AAA by means of the component patterns corresponding to CM EVe, etc. [1].

The use of EVa and Eve of the estimate of a priori unknown CM by ES methods determines the dependence of the quality of generated estimates (dispersion and bias) of measured quantities (frequency of harmonic components of signals during the time-domain spectral analysis, the arrival direction (AD) of signals of radiation sources during the spatial spectral analysis) on the quality and properties of CM estimate (the size of the learning sample used for estimation, rank of the sample CM, the use of a priori information, etc.) [1–7].

In practical operation conditions of radio-technical systems (RTS) the sample size is finite and small. For example, in case of the processing of signals in antenna array (AA) and using the maximum likelihood estimate of CM of observed data in general form, the small size of sample is characterized by condition $K < m$, where K is the number of samples (pictures), m is the number of antenna elements. In case of small sample size the sample CM is degenerate and its inverse matrix does not exist [1–7]. In such conditions the implementation of adaptive procedures of AAA tuning by the criterion of maximum of signal-to-noise ratio is possible at the expense of regularization (diagonal weighing) of sample CM of input data [1, 5, 7] and the use of a priori information about the presence of white noise in the interference [7]. For a regularized CM estimate the sample is small at $K < 2V$, where V is the number of radiation sources (harmonic components of signal). In this case the reserve for enhancing the RTS effectiveness consists in using additional information about the CM structure during its estimation [1, 5, 7].