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Analysis of the Prony Method Performance with Linear Vector-Scalar Antenna

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Abstract

A modification of the Prony method which allows using this method for processing signals received by the vector-scalar antenna is proposed. The efficiency of the Prony method is considered when working with the various components of the acoustic field: a scalar, vector, and power flow components. Analysis of characteristics of the Prony method is done using computer modeling by averaging estimates of the parameters of the received signals on a set of random realizations. Computer modeling has allowed more fully taking into account the energy, space-correlation and statistical characteristics of vector-scalar field of noise. The calculations are carried out for the conditions most close to reality when the antenna operates in the background of dynamic noise of sea. Presentation of results of the signal parameters estimation by the Prony method in the form of a histogram in the spatial domain has allowed to give a visual assessment of the characteristics of this method in the various components of the acoustic field and to increase its efficiency.

Keywords: *Vector-Scalar Antenna, Prony Method, Noise of the Sea, Standard Errors, Signal/Noise Ratio.*

1. Introduction

Recent years, in solving various problems of applied underwater acoustics, algorithms are intensively studying the efficiency of which is increased by the measurement of not only a scalar, and vector components of the acoustic field at each point in space. Analysis of the performance of signal processing algorithms for vector-scalar receiving systems plays an important role in creating the most advanced sonar systems.

However, to date the modern algorithmic apparatus for vector-scalar receiving systems, in large part, is a logical extension of the algorithms used for scalar systems. Moreover, in such a way that the signal processing techniques for scalar systems are a special case of methods for vector-scalar receiving systems. For example, in the paper [1] a general approach is presented to the modification of algorithms with standard and high resolution with respect to the vector-scalar receiving system. In this paper, it is also shown that the calculation of the potential accuracy of the estimation of parameters of random signal using a vector-scalar systems, distributed by the normal law, can also be performed using the Fisher information matrix [2]. The similar approach was used in [3] in the analysis of the Capon method having a high resolution, as well as in the study of methods for ultra-high resolution ESPRIT, ROOT-MUSIC and MUSIC [4-6].

Numerous studies of the characteristics of algorithms for vector-scalar antennas show that their effectiveness (signal to noise ratio at the output of the receiving system) increases only 3-5 times in comparison with scalar receiving system [7-9]. However, authors of [10] have obtained theoretical relationships, indicating that the power flow in the measurement of signal/noise ratio at the output of the receiving system can be ten times higher than in the measurement of scalar field component. Thus, it is clear that there is a contradiction in the assessment of the possibilities of vector-scalar receiving systems. The similar contradiction is discussed in papers [11, 12] in relation to the detection algorithm using a single vector-scalar receiver. Only in [13-15], have been developed algorithms of suboptimal spatial filtering, built on measuring only the power flow, and it was shown that the signal to noise ratio at the output of the receiving system can be increased by 10 times or more. These studies have shown that the joint usage of scalar, vector, and power flow components of the field do not reach estimates obtained in [10]. In solving problems of direction finding, a special place occupies the parametric Prony method [16]. Previously, it was believed that the embodying and analysis of the characteristics of this method requires a lot of memory, and high performance computing facilities, however, this obstacle was overcome due to the increased computing capabilities of digital technology. That is why in recent years the number of publications on the use of the Prony method has increased significantly to solve a wide variety of tasks. However, the development of the Prony method for vector-scalar receiving antennas is presented only in [17-19]. Since the characteristics of the vector-scalar noise fields are substantially different from the characteristics of the noise scalar fields [20, 21], the purpose of this study is the analysis of the Prony method performance with the various components of the vector-scalar acoustic field. To study the algorithms, computer modeling is used which allowed to perform the analysis on the basis of a comprehensive approach, including both simulation of vector-scalar noise fields [21, 22], and the modeling of signal processing algorithms for vector-scalar receiving systems.

2. Model of Signal and Noise

A distinctive feature of this study is investigation of the vector-scalar receiving systems operating at background of sea noise. Therefore, it is assumed that a signal from a local source is received together with noise. Figure 1 shows a schematic representation of the geometry of the problem. A point source, whose parameters must be defined, emits a signal having the properties of white Gaussian noise with zero mean. The antenna consists of M vector-scalar modules. Each module is formed by the pressure receiver P and two orthogonal vector receivers (the Vx and Vy) with a single phase center (Figure 2).

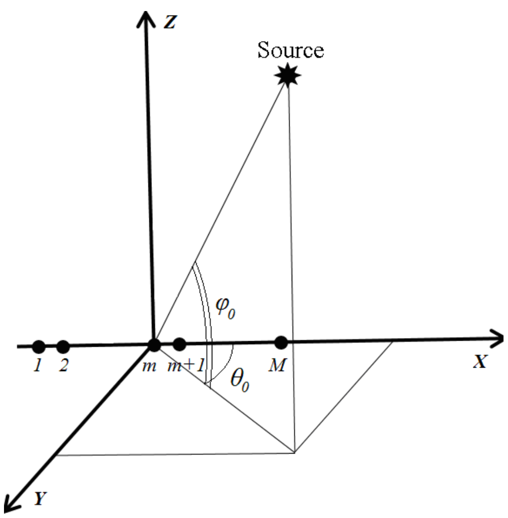

Fig. 1 The geometry of the problem in three-dimensional space, θ_0, φ_0 are angular coordinates of source (azimuth and elevation).

After narrowband filtering, the sound field in a free space created for *m*-th receiving antenna element with a local source of power equal to A, is written in the form

$$P_m = \frac{\sqrt{A}}{r_m} \exp(-jkr_m) \quad (1)$$

where $k = 2\pi/\lambda$ is wave number, λ is wavelength, r_m - the distance between the source and the *m* - receiver antenna. Expressing the vibrational velocity of particles in equivalent units of sound pressure by the formal multiplication of oscillatory speeds on impedance ρc of environment we have

$$V_x = P\cos\theta_0 \sin\varphi_0,\ V_y = P\sin\theta_0 \sin\varphi_0,\ V_z = P\cos\varphi_0. \quad (2)$$

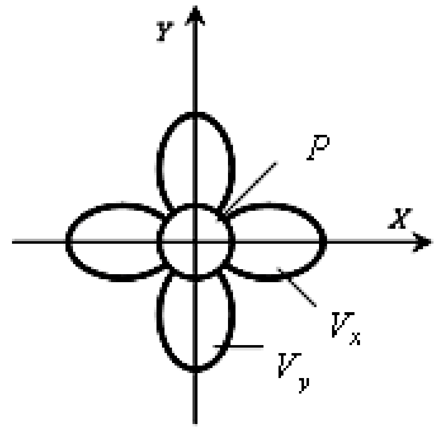

Fig. 2 Schematic representation of the 3-component vector-scalar module.

Authors of [20] have shown theoretically and experimentally that the presentation of vector components of the signal in the form of (2) is valid both for propagation in free space and in a waveguide, if the relation k • Hw> 3 is carried out (Hw is a waveguide depth). The received signals are represented as a column vector:

$$\mathbf{U} = \begin{pmatrix} \mathbf{P} \\ \mathbf{V}_x \\ \mathbf{V}_y \end{pmatrix} \quad (3)$$

where P, Vx, Vy are the M-dimensional vectors, the components of which correspond to the signals received by vector-scalar antenna. For sound pressure $P = (P1, P2, ..., PM)^H$, and for vector components $Vx = (P1, P2, ..., PM)^H \cos\theta_0 \sin\varphi_0$ and $Vy = (P1, P2, ..., PM)^H \sin\theta_0 \sin\varphi_0$, $(\bullet)^H$ denotes the Hermitian conjugation, where P, Vx, Vy are the M-dimensional vectors, the components of which correspond to the signals received by vector-scalar antenna.

To calculate the vector-scalar noise formed by the rough surface a physical model of the noise source for scalar field component is used. This model was confirmed by numerous experimental data [23]. According to this model, sea noise is generated by set of independent point sources uniformly distributed over the surface of the sea. Each source has oriented in direction $g = \sin^n \varphi$, where φ is the angle of elevation (Figure 1). Experimental data suggest n ~ 1, even when the wind speed is up to 15 m/s. Based on this, the acoustic pressure on the *m*-th receiver of the pressure for the noise component can be calculated as a set of signals from random sources located on the sea surface with uniform density distribution

$$p_m = \sum_{i=1}^{\infty} S_i \cdot \frac{\exp(-j \cdot k \cdot r_{im})}{r_{im}} \cdot g \quad . \qquad (4)$$

There r_{im} is the distance from the *i*-th noise source on the sea surface to the *m*-th element of the receiving antenna. It is believed that random amplitudes of sources S_i are distributed by Rayleigh and the initial phases are uniformly distributed in the interval from 0 to 2π. Imaginary and real parts of such signals are normally distributed. To calculate the noise vector on receivers of the *m*-th module, the scalar components of the signal that came from each source should be multiplied by $\cos\theta_i \sin\varphi_i$ and $\sin\theta_i \sin\varphi_i$ for V_x and V_y component, respectively (θ_i, φ_i are azimuth and elevation angle of the *i*-th noise source). The ratio of noise power at the vector receiver, the axis of which is oriented in the horizontal plane, to the noise power at the sensor depends on a scalar ratio Hw/λ, and may range from 0.25 to 0.5. This ratio is equal to 0.25 for the deep sea [24]. The number of noisy sources (4) is chosen so that the diagonal elements of the covariance matrix (power on scalar and vector receivers) corresponded to their ratio in the deep sea. In addition, the spatial correlations for all the components of the acoustic field must also comply to known dependencies for deep sea [21, 22, 24].

For Gaussian signals and noise with zero mean, statistics of measurements are completely determined by covariance matrix, which is calculated for a given model signals and noise as a $K = U \cdot U^H$. Matrix K with size of 3M × 3M has the block form:

$$\mathbf{K} = \begin{pmatrix} \langle \mathbf{P}\cdot\mathbf{P}^* \rangle & \langle \mathbf{P}\cdot\mathbf{V}_x^* \rangle & \langle \mathbf{P}\cdot\mathbf{V}_y^* \rangle \\ \langle \mathbf{V}_x\cdot\mathbf{P}^* \rangle & \langle \mathbf{V}_x\cdot\mathbf{V}_x^* \rangle & \langle \mathbf{V}_x\cdot\mathbf{V}_y^* \rangle \\ \langle \mathbf{V}_y\cdot\mathbf{P}^* \rangle & \langle \mathbf{V}_y\cdot\mathbf{V}_x^* \rangle & \langle \mathbf{V}_y\cdot\mathbf{V}_y^* \rangle \end{pmatrix} =$$

$$= \begin{pmatrix} \mathbf{\Gamma}_{11} & \mathbf{\Gamma}_{12} & \mathbf{\Gamma}_{13} \\ \mathbf{\Gamma}_{21} & \mathbf{\Gamma}_{22} & \mathbf{\Gamma}_{23} \\ \mathbf{\Gamma}_{31} & \mathbf{\Gamma}_{32} & \mathbf{\Gamma}_{33} \end{pmatrix}, \qquad (5)$$

namely, it is the sum of the signal and noise matrixes. Each of the three sub-matrixes of size *M* × *M* (5), standing on the main diagonal, describes the covariance dependence between the same components of the vector-scalar field, and the off-diagonal - their mutual covariance. Sub-matrixes with size of *M* × *M* are designated as Γ_{ij}, *i*, *j* = 1, 2, 3.

3 Algorithm of Processing

If the equidistant horizontal linear array consisting of *M* elements receives *L* signals in the form of plane waves, each of the sub-matrixes Γ_{ij} (5) is Toeplitz. Summing values of elements of sub-matrices whose indices satisfy the condition $l - m = const$, we obtain a vector that is denoted $\mathbf{F}_i$. With reference to the upper diagonal sub-matrix $\mathbf{\Gamma}_{11}$ = P P * theoretical values of the vector components $\mathbf{F}_i$ when receiving signals from *L* local sources may be represented as

$$F_i(n) = \sum_{l=1}^{L} A_l x_l^n \quad n = 0, 1, ..., 2M-1, \qquad (6)$$

here value A_l corresponds to power of *l- th* local source, $x_l = \exp(-j\,\xi_l)$, where ξ_l is a difference in phase of a signal from *l-th* local source in two next receiving elements. If the source is in a far zone of a receiving antenna the angle of elevation φ is small, hence, parameter ξ_l is related to a spatial angle of arrival of a signal from *l-th* local source by a relation $\xi_l = kd \cos_{\theta l}$, where *d* is distance between elements of receiving antennas, θ_l is a direction on a source (azimuth), digitized from axis *X* along which receiving modules are located.
Using following labels

$\boldsymbol{\beta}_l = \begin{cases} \boldsymbol{A}_l \\ \boldsymbol{A}_l \cdot \cos\boldsymbol{\theta}_l \\ \boldsymbol{A}_l \cdot \sin\boldsymbol{\theta}_l \\ \boldsymbol{A}_l \cdot \cos^2\boldsymbol{\theta}_l \\ \boldsymbol{A}_l \cdot \sin^2\boldsymbol{\theta}_l \end{cases}$	for	$\mathbf{\Gamma}_{11}$ $\mathbf{\Gamma}_{12}$ $\mathbf{\Gamma}_{13}$ $\mathbf{\Gamma}_{22}$ $\mathbf{\Gamma}_{33}$	(7)

for each of the sub-matrixes $\mathbf{\Gamma}_{ij}$, we obtain the systems of equations

$$F_i(n) = \sum_{l=1}^{L} \beta_l x_l^n, \qquad n = 0, 1, ..., 2M-1 \quad . \qquad (8)$$

For these equations, the scheme of finding the unknown parameters of signals by the method of Prony [16] for the undamped exponential is applied. In this non-linear system of equations *xl* and *βl* are unknown complex quantities. Unknown xl are found as the roots of a polynomial

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$$x^L + \gamma_1 x^{L-1} + \ldots + \gamma_L = 0, \qquad (9)$$

coefficients of which satisfy the system of linear equations

$$F_{n+L} + F_{n+L-1}\gamma_1 + \ldots + F_n \gamma_L = 0, \qquad n = 0, 1, \ldots, 2M-1. \qquad (10)$$

After finding the values x_l, they are substituted into (8) and the resulting over-determined system of linear equations is solved (L<2M) concerning to β_l, which is uniquely associated with the signal strength. To solve the over-determined systems of equations (8) and (10) the method of least squares is used.

Analysis of characteristics of the Prony method is done using computer simulation by means of averaging estimates of the signal parameters from a local source on the set of random realizations. The calculated RMS estimates of signal parameters are compared with the potential accuracy which corresponds to the lower boundary of the Cramer-Rao [2] in the processing of signals from the vector-scalar antenna. In this case, the variance estimates of required parameters of local source are determined by the diagonal elements of the error matrix

$$\sigma^2(\alpha_i) = (\mathbf{I}^{-1})_{ii}, \qquad (11)$$

where **I** is the Fisher information matrix, elements of which are calculated using the covariance matrix of the received signals K

$$I_{ij} = Tr(\mathbf{K}^{-1} \frac{\partial \mathbf{K}}{\partial \alpha_i} K^{-1} \frac{\partial \mathbf{K}}{\partial \alpha_j}), \qquad (12)$$

here α is vector of unknown parameters of the source, which for this problem consists of two components: an azimuth and power source.

4. Simulation Results and Discussion

It is obvious that, during the propagation of signals in inhomogeneous stratified medium, estimation of the signal arrival directions in the horizontal plane will fluctuate, and these fluctuations are due to a propagation conditions and the presence of noise. In this paper we analyzed the effect of the latter factor.

Calculations are performed for the vector-scalar receiving array consisting of 21 modules, each of which represents a three-component receiver including two scalar sensor and vector sensor orthogonal axes of which located in a horizontal plane. The antenna is mounted horizontally, the antenna aperture at inter-element distance d = 0.5 m is 10 m. The average frequency of the operating range is f = 1,000 Hz. The distance to the source is 3000 m. The direction of the source measured from the axis of the antenna is equal to 45 °. When the antenna aperture is 10 m, and a frequency is 1 kHz it can be assumed that the local source is in the far field of receiving antenna.

By using various components of the vector-scalar acoustic field, standard errors are calculated for estimation of azimuth and signal power based on the signal/noise ratio at the input of the receiving system (Figure 3). S/N ratio is specified for the pressure receiver. Search of solutions for the scalar component of the acoustic field uses only a block of data from the sub-matrix covariance Γ_{11}. Search of solutions for vector component uses a data block composed of sub-matrixes Γ_{22} and Γ_{33}. Power flow components use block consisting of sub-matrixes Γ_{12} and Γ_{13} (hereinafter in the figures, these three components are designated P, V and W, respectively). For each of the realizations for which standard errors are calculated, all blocks Gij belong to the same simulated covariance matrix K.

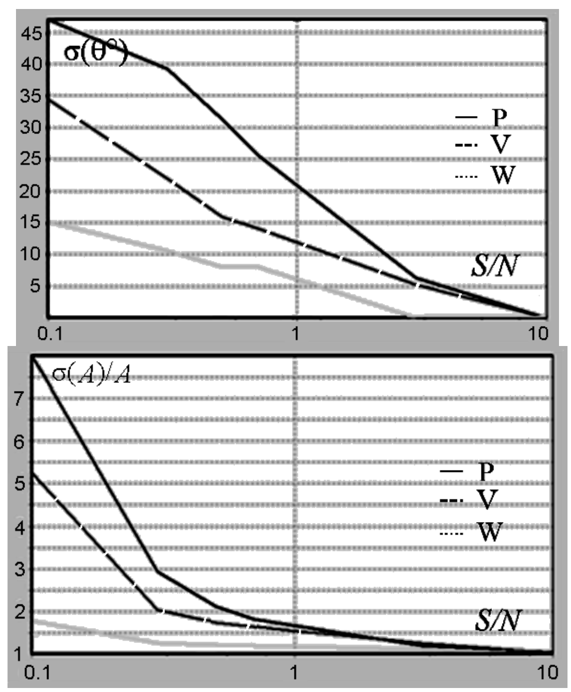

Fig. 3 The RMS error of the estimate of azimuth (a) and power (b) of the source (θ_0 = 45 °) depending on the S/N ratio at the input of the receiving system by using different vector-scalar components of the acoustic field.

As seen from the obtained data, the algorithm used the power flow components has standard errors and bearing capacity evaluation that are about 3 times less than when working with scalar components of the field. This result is predictable, because, in accordance with the theoretical and experimental data, the noise power in components of the power flow in the horizontal plane is much smaller than the noise power in the scalar and vector components [20]. The mean value of the noise power flow is zero, because the pressure and the vector components in the horizontal plane are uncorrelated (with infinite observation time and an isotropic distribution of noise sources on the sea surface), but correlation of these components is maintained for a signal from a local source. Therefore, signal/noise ratio at the input of the receiving system for power flow component is less than for scalar and vector components what is confirmed by experimental data presented in [25]. According to the experimental data presented in [20], in the real dynamics of the open ocean the noise is in the frequency range of 200-1000 Hz, and this ratio can reach 20-30 dB. As a consequence, the accuracy of the source parameter estimates for the power flow component is higher than for the other components of the field. Figure 4 provides estimates of potential accuracy of azimuth and signal power for the same signal - interference situation as in Figure 3.

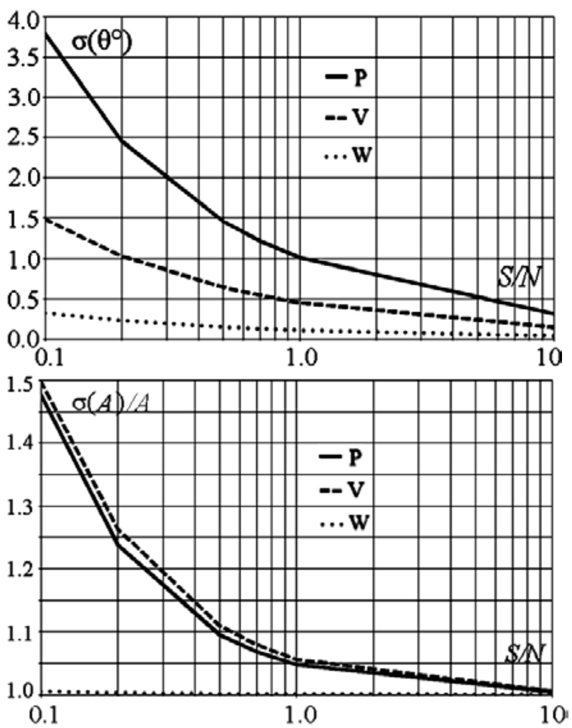

Fig. 4 The potential accuracy of the estimation of azimuth (a) and the power (b) of the source (θ_0 = 45 °) depending on the S/N ratio at the input of the receiving system by using different vector-scalar components of the acoustic field.

The calculations are performed in accordance with the expressions (11, 12), but replacing in the expression (12) the covariance matrix K by blocks Γij, which focused the measurement of scalar, vector, or the power flow components of the field. Matrix of interferences, caused by the sea noise, calculated like for the Prony method using computer simulation (5).

Comparison of the mean square error of the parameter estimates, corresponding to the Prony method, and potential accuracy shows that at low S/N ratio at the input of the receiving system (S/N<1) the error is much larger than the lower Cramer-Rao boundary for each of the components of the acoustic field. Thus, when assessing the azimuth using the scalar components this error is 10 times greater, and with the use of power flow components error is 40 times greater. By increasing the S/N up to 10, precision of signal source parameter estimates is approaching potential accuracy. The calculation results and the standard errors of the potential accuracy of signal parameter estimates, depending on the angle of arrival with respect to S/N = 1 are represented in Fig.5.

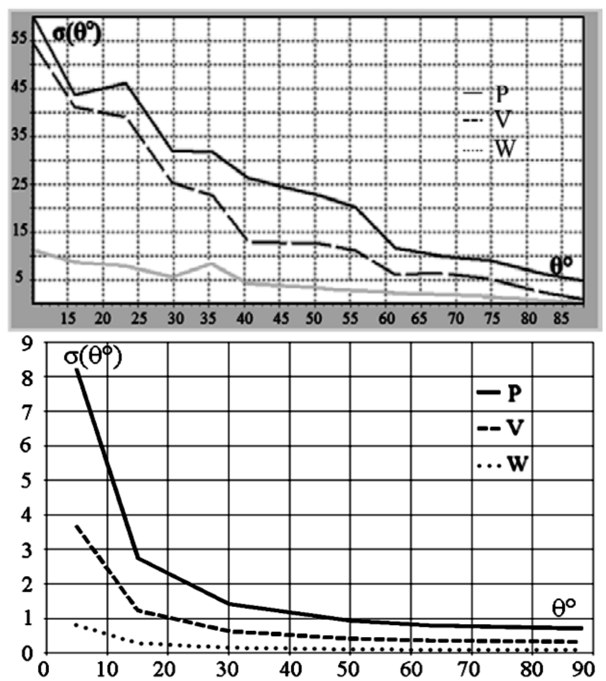

Fig. 5 The mean square error of the azimuth estimation (a) and a potential accuracy of estimation of source azimuth (b) depending on the angle of arrival by using the various components of the vector-scalar acoustic field (S/N = 1).

It is evident for the Prony method that dependence of errors on the signal arrival direction is of the same nature like the optimal method, which corresponds to the lower Cramer-Rao boundary. When the source (direction) is

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approaching to the axis of the antenna, errors are increased what is explained by an increase of the width of the main lobe for spatial filtering methods. As in the previous case, the comparison of standard error of estimates of the parameters corresponding to the Prony method and potential accuracy shows that the work with all the components of the acoustic field provides error about 10 times greater than the lower boundary of the Cramer-Rao. A similar result was obtained in a number of papers dealing with the use of the Prony method for various applications, for example, in [26], which deals with the use of the Prony method for spectral estimation of the two-dimensional signal.

For a clearer analysis of the Prony method we propose a local representation of the source parameter estimates as a histogram in the spatial domain. To this end, the obtained estimates of the signal power A and azimuth θ, calculated on 100 realizations, are used to construct the dependence Φ(θ): powers of signals trapped in a given spatial angle range are added up. As a result of this transformation an analogue of spatial spectrum (histogram in the spatial domain) is obtained. Figure 6 shows the dependence of Φ(θ), obtained for the given signal - interference situation.

Results are presented as three curves corresponding to usage of a scalar (R), vector (V) and a power flow (W) component of the acoustic field. The left side of the Figure shows the spatial spectrum in the range from 0 to π, and in the right part of the spectrum is allocated in the area of the true direction of the source signal.

The data show that the solution of equations (6) gives the false roots, the number of which increases when the S/N ratio at the input of the receiving system decreases. The power of the false roots also increases with decreasing ratio S/N, what is typical for increasing of the lateral background in spatial spectra. The number of false roots equals 71, 69 and 52 for the scalar components, 60, 58 and 36 for the vector components, and 47, 40 and 33 for power flow components at S/N = 0.0 1, 0.1 and 1, respectively. The number of false roots was calculated throughout a range of angles from 0 to π, except interval $\theta_0 \pm 2$ near the true direction of the source.

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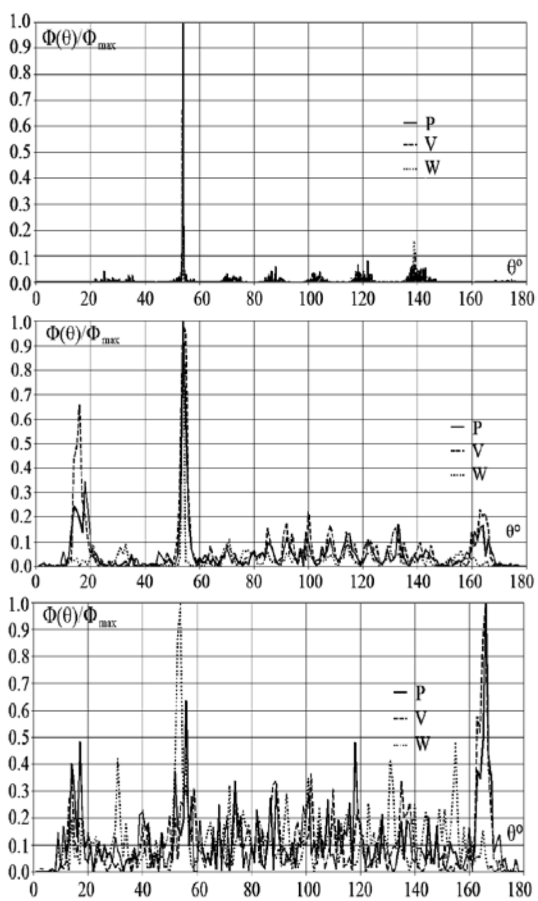

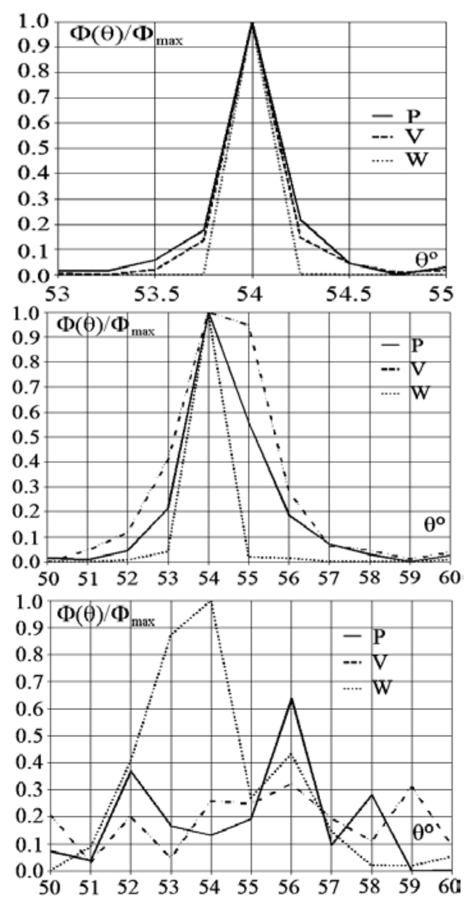

Fig. 6 The spatial spectrum of the Prony method (left) and an enlarged portion of the graphs in the area of the true value of the azimuth (right side); Signal processing is performed using a scalar (R), vector (V) and a stream (W) component of the acoustic field; the ratio S/N = 1 (a), S/N = 0.1 (b), and S/N = 0.01 (c), the true direction of the local source θ_0 = 54°.

The number of false roots equals 71, 69 and 52 for the scalar components, 60, 58 and 36 for the vector components, and 47, 40 and 33 for power flow components at S/N = 0.01, 0.1 and 1, respectively. The number of false roots was calculated throughout a range of angles from 0 to π, except interval $\theta_0 \pm 2$ near the true direction of the source.

For the case of S/N = 1, the direction of the source in any component of the acoustic field is given by δ - function, but the presence of false roots whose position is far from the true value, considerably increases the standard errors of estimation of direction to the source with a standard approach to their calculation (Figure 3). At lower S/N ratio, main lobe expands and the number of false roots is increased. That is, the standard approach to the calculation of characteristics of the Prony method shows that it is possible to estimate the direction of signal arrival only for the ratio S/N>>1, while the presentation of the results in the form of spatial spectrum allows determining the direction of signal arrival with sufficient accuracy for a scalar component for a ratio S/N = 0.1, and for the power flow component even for S/N = 0.01. This is because the contribution to the standard errors for the standard approach is provided by all the roots found, which are distributed in a range of angles from 0 to π. Thus, switching to a spatial spectrum is needed to recalculate the standard errors of the azimuth estimates in the main lobe of the spatial spectrum, like it is usually done in the calculation of the characteristics by spatial filtering techniques.
Figure 7a shows the results of the standard errors of azimuth estimates, and Fig.7b - results of numerical calculation of one of the main characteristics of the receiving system - the signal/noise ratio at the output of the receiving system, calculated according to the equation [2]

$$d = \left. \frac{\langle \Phi(s+n) - \Phi(n) \rangle}{\sigma(\Phi(n))} \right|_{\theta=\theta_0}, \quad (13)$$

where $\langle \Phi(s+n) \rangle$ is the average value of the spatial spectrum when receiving the additive mixture of the useful signal and noise, $\langle \Phi(n) \rangle$, $\sigma(\Phi(n))$ are the mean and standard deviations of the spatial spectrum of the noise at reception only. Calculations of the signal/noise ratio at the output of the receiving system and the mean square error of azimuth estimation are performed for 1000 realizations of the spatial spectrum, an example of which is shown in Figure 6. Since the value of d determines unambiguously other characteristics, including a false alarm probability and correct detection, the calculation can be restricted only by this value.

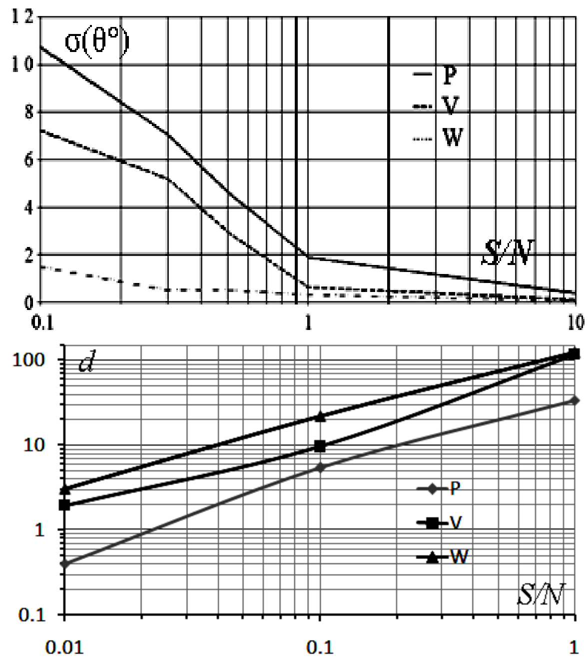

Fig. 7 The RMS error of the estimation of azimuth (a) and signal to noise ratio at the output of the receiving system (b) depending on the S/N ratio at the input, obtained for the case where the results of the Prony method is presented in the form of the spatial spectrum.

Analysis of the obtained results for the given signal noise situation allows to draw the following conclusions: (1) the standard errors of azimuth estimation for the Prony method obtained on the basis of the spatial spectrum (Figure 7) provide values that are closer to the bottom border of the Cramer-Rao for each component of acoustic field (Figure 4); (2) satisfactory detection of signal source (d ≥ 3) is achieved when the ratio of S/N at the input of the receiving system is equal to S/N> 0.1, and S/N> 0.01 for scalar and power flow components, respectively. Thus, the presentation of the results of the Prony method in the form of the spatial spectrum indicates its potential.

It should be emphasized that detection and estimation of signal parameters are more efficiently with a power flow component than with scalar or vector component.

To confirm the advantages of power flow components below are presented the results for more complex situation when the input of the antenna receives signals from two

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local sources in the direction of θ1 = 44 ° and θ2 = 54 °. The spatial spectra are given in Fig 8 for the signal processing of various components of the vector-scalar field: scalar (R), vector (V), and a power flow (W).

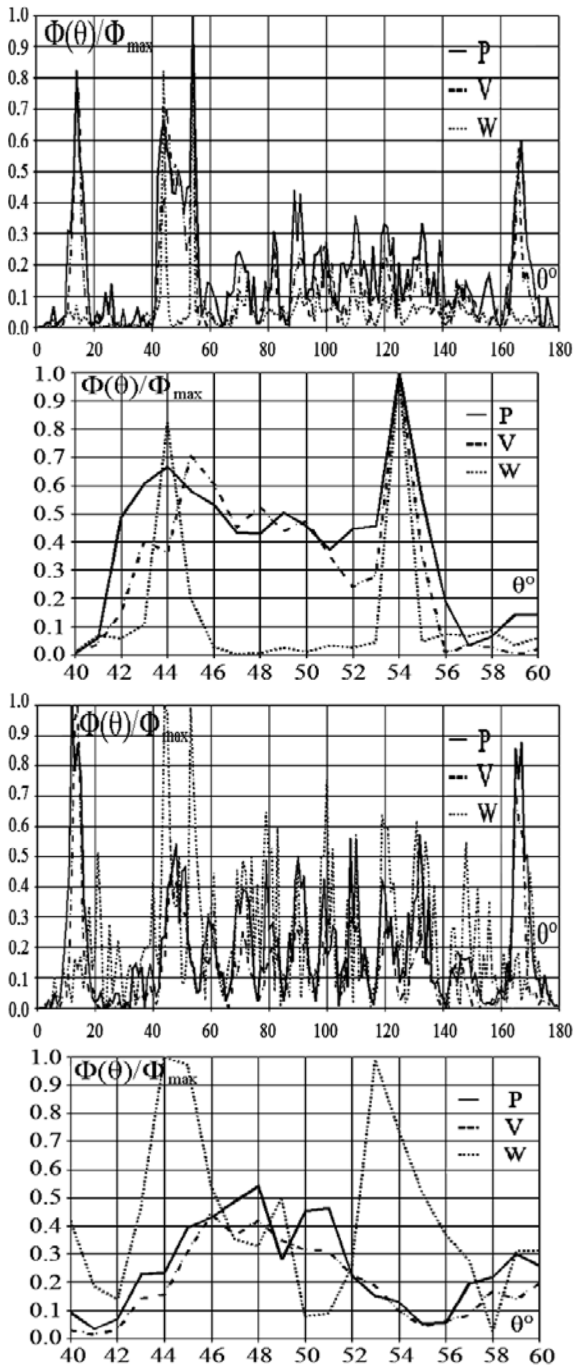

Fig. 8 The spatial spectrum of the Prony method (left) and enlarged part of the graph near the true value of azimuth (right side); Signal processing was performed using a scalar (R), vector (V) and a power flow (W) component of the acoustic field, the ratio S/N = 0.1 (a) and S/N = 0.01 (b); the true direction of the signal sources is equal to θ_1 = 44 ° and θ_2 = 54 °.

Indeed, the results of Figure 8 show that in case of S/N = 0.1 streaming only the use of power flow components of the field (W) allows resolving the two sources, besides, the source direction evaluation is not shifted without significant side lobes. With the use of scalar and vector components of the field only one of the signals is allocated well. Furthermore, the spatial spectra corresponding scalar (P) and a vector (V) components have side lobes that may be identified as false targets (left panel of Fig.8). Thus, when S/N = 0.01 spatial spectra using scalar and vector components have the maximum values in the 17 ° and 165º, which does not correspond to the direction of signal sources. But when working with a power flow component two targets can be resolved. The presence of the side lobes for level ~ 0.7 can also be interpreted as the presence of the source signals. But if the detection threshold is above 0.7, which is quite legitimate, as the average noise level in the spatial spectrum for all the components of the field rises to these values, then we can talk about the possibility of detection and resolution of two closely spaced sources, even with S/N = 0.01.

5. Conclusion

The usage of computer modeling showed the applicability of the Prony method for processing signals received by the vector-scalar antenna, allowed to compare its efficiency when working with the various components of the acoustic field in identical, and most close to the real conditions when the antenna operates in the background of noise of the sea. The calculations showed that for the algorithm using the streaming component of the field, error of the azimuth and RMS power estimation is much smaller than for scalar or vector components of field. This is because the noise of the sea varies greatly for a scalar, vector, and power flow components. Thus, in the same conditions, power flow noise component is 10-100 times less than the scalar component. Hence, using vector-scalar antennas can significantly improve the performance of the Prony method in a receiving system at background noise of the sea. The traditional approach of investigating the characteristics shows that the standard errors of the parameter estimates using the Prony method is about 10 times larger than the bottom Cramer-Rao limit.

This paper proposes a way of representation of the results of estimating the parameters of signals by the Prony method in the form of the spatial spectrum. This way is sufficiently informative, suggesting a possible improvement of both the Prony method and an analysis of its characteristics, and can be used as a basis for further research of the method.

The calculation of standard errors by the Prony method in the main lobe of the spatial spectrum, as it is usually done in the calculation by the spatial filtering methods shows that the characteristics of the Prony method are close to the Cramer- Rao border.

Modification of the Prony method allows presenting the results of its work on the basis of spatial filtering. Thus, not only the scope of applicability of this method was expanded, but an increase of noise stability was shown. initial capitals.

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