Overview of Online Radiation Source Orientation

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Abstract:
The study has synthesized the theoretical basis, the radio radiation source direction algorithm and some structural models of the antenna array on a linear algebraic basis. With the purpose of improving the quality of direction of radio radiation sources, the thesis has researched a number of solutions to solve two basic problems: Accuracy, resolution and computational complexity; Problems with the effect of color noise and a priori information uncertainty in the number of radiation sources:

Keywords: *Direction of radio radiation source*

1. Introduction

The orientation of radiation sources plays an important role in all areas of social life and especially for Security - Defense [1], [2], [5], [6]. This field has been and is being studied by domestic and foreign scientists to solve many problems in practice such as earthquakes, tsunamis; aerospace; rescue and rescue; hydrographics ... Orientation of radio radiation sources is the content of the above issues applied in many fields such as radar, radio surveillance, frequency management, rescue and rescue, aerospace, optimization in communications, reconnaissance, electronic warfare and many other fields.

The problem of directing radio radiation sources (referred to as radiation sources) has been studied and applied for a long time by scientists to determine the direction of incident waves of radiation sources propagating in space. On the basis of information about the direction of the incident waves, it is possible to find radio interference sources, locate unauthorized sources as well as apply in radio navigation.

There are many ways to classify radiation source-oriented systems, but the most common is usually based on the system structure and the signal processing method.

• Based on the system structure:

Single-channel directional system: This system uses a multi-element antenna array where each element is connected in common with a receiver via high-frequency switching. The signals received from the antenna elements are processed to determine the direction of the incoming waves.

Multi-channel directional system: This system uses a multi-element antenna array where each antenna element is connected to a receiver. Each receiver acts as a signal preprocessor. The receiver output signal is sent to a signal processing unit to determine the direction of the incident waves.

The single-channel directional system, despite its simple, compact but medium-precision receiver architecture, complex processing algorithms, high-frequency switches require high speed. Some commonly used techniques for this type of system include: Wattson - Watt, Doppler and pseudo Doppler, PLL.

The multi-channel directional system is cumbersome in architecture, has a more complex processing algorithm, but has the advantage of high accuracy and resolution, and is capable of simultaneously identifying multiple wave directions towards the antenna array. Some commonly used algorithms for this type of system include: MUSIC, ESPRIT, PM, correlation vector, Barlet, Capon, linear prediction, maximum Entropy.

Today, the multi-channel orientation system is interested and used more in practical applications. The development of computer engineering as well as microelectronics technology (e.g. receiver defined by SDR software) has allowed reducing system size, flexible structure in software, speed of processing. Process faster and consume less power.

• Based on signal processing method:

System using phase comparison method: According to this method, multiple receiver antennas are arranged to ensure that the relative phase of the induced voltage across the antennas is unique for each incident wave direction. This direction is calculated based on the relative phase of the signal per antenna element.

System using amplitude comparison method: According to this method, two or more directional antennas are arranged so that the relative amplitude of the voltage across the antenna array is unique for each incident wave direction. The incidence angle is calculated on the basis of the relative amplitude of the signal on the antenna elements.

- A directional system using the amplitude-phase method: This is a system that determines the direction of the incident waves based on both the amplitude and phase of the signals received by antenna elements.

2. Literature review

- Regarding the problem of radiation source orientation:

Initially, in 1925 and 1926, British scientist Robert Watson-Watt was a pioneer in the field of radio navigation. By 1931, products of this engineering application were equipped with the British army. After 1943, the complete navigation system was put into service during World War II. It was also around this time, in 1941, that the Doppler principle orientation technique also began to be of greater interest.

In 1967, Burd proposed a method to evaluate the MEM spectrum and was developed in the following years by many authors including Lang, McClelan (1982) [43]. The basic content of this method is to maximize the Entropy function. In this direction, there are many algorithms developed to solve the nonlinear optimization problem such as AR, MA, ARMA. All above algorithms have high resolution but require large computation time and low stability [52], [100].

In the early 1970s, the advent of digital technology created new changes in the field of radio navigation. Products applying this technology began to apply in areas such as: radio orientation, radiation source positioning and digital control.

By 1980, researchers had come up with a series of algorithms that evaluate the signal spectrum based on individual values. Representative of this method is MUSIC algorithm proposed in 1980 by author Schmidt [22], [63]. At that time, MUSIC was better than any other method and received high appreciation for its accuracy and ability to direct multiple radiation sources simultaneously. However, MUSIC has the disadvantage of requiring a lot of calculation and inability to direct the correlated radiation sources. In terms of mathematics, the MUSIC algorithm is a complete of the maximum Entropy method with the same properties as the maximum rational method [31], [56]. An improved form of the well-known MUSIC algorithm is Root-MUSIC [61]. This algorithm has better quality than MUSIC due to the reduced computation time [74].

In 1986, R.L. Johnson and G.E Miner [38] have presented quite in detail the super high resolution algorithms with the following summary content:

- MLM method: MLM energy spectrum is described by the direction vector of the antenna array and spatial correlation matrix [70].

- AAR method by Borgitti, Kaplan [10] and developed by Lagunas- Hernandez, Gasull-Lampllas [42]. In general, this method is the same as the improved MLM [2].

- TNA algorithm proposed by Gabriel gave a spectral evaluation method using the limit of heat noise [23].

- MEM method: In this method, an iterative technique is used to reduce computation time [23].

In 1989, the ESPRIT algorithm was proposed by Roy and Kailath which used the constant quantity circulating in the signal space [64]. This space is made up of two arrays with a translational invariant structure. ESPRIT and improved algorithm TLS-ESPRIT has super high resolution. The advantage of these algorithms is that they reduce computation time in spectral search, which in turn can speed up orientation. However, ESPRIT and its improved versions cannot be applied to the UCA antenna nor to the direction of the correlated radiation sources [25]. Therefore, the application has many limitations.

Also at this time, the method of directing the correlated radiation sources was also of interest to many scientists. In 1985, the authors T. J. Shan, M. Wax and T. Kailath introduced the space smoothing method. By 1989,

S. U. Pillai and B. H. Kwon developed into the reversible space smoothing method [46], [57]. Under this method, the antenna array is divided into sub-antenna clusters. The covariance matrix is then constructed by averaging all the sub-matrices created by those sub-antenna clusters. This method allows to break down signal correlation but the computational complexity is often very large.

After the 1990s, more attention was paid to the rapid orientation methods. The term "Pencil" was first proposed by Ganmacher in 1960 [27]. Then, Matrix Pencil algorithm was first introduced by author Y. Hua and T. K. Sarkar in 1990 [33]. In 1995, authors T. K. Sarkar and O. Pereira continued to develop this algorithm [66]. Basically, the aim of the above studies is to solve the orientation problem with only one observed signal sample. By 1996, the author R. Adve applied this algorithm in the medium signal environment [8]. However, this algorithm has a low resolution and is only suitable for applications with large SNRs.

In 1991, J. Munier and G. Y. Delisle introduced a spectral evaluation method using cross correlation matrices [53]. In 1995, S. Marcos, A. Marsal and M. Benidir proposed the PM algorithm to determine the azimuth [50]. Both of these proposals allow for the reduction of computational complexity by not having to implement eigenvalue expansion. However, this method is only suitable for Gaussian white noise. Quality is greatly degraded under nonlinear noise conditions or small SNRs.

Since 2000, along with the rapid development of computer engineering, antenna engineering, signal processing, directional methods have been studied in the direction of increasing accuracy and resolution, speeds up the orientation, being able to define more parameters.

Considering the directional control method, array array antennas are widely used in today's directional systems thanks to the many advantages of phase distribution control [1]. There are two typical types of phase array antennas: ULA and UCA [11], [79], [96]. Unlike ULA, the UCA antenna array allows orientation in both the elevation and azimuth [39]. Besides, some other types are also interested by many authors in 2D orientation such as: L-shaped antenna array [34], [87], [88]; URA [62], [99], [101].

In terms of signal processing, Hermitian Toeplitz matrix has been used by some authors in the orientation of radiation sources relative to only one observed signal sample. In 2005, author Kareem A. Al Jabr proposed UCA-ESPRIT and UCA-ROOT-MUSIC algorithm using Hermitian Toeplitz matrix applied to UCA antenna array [39]. In 2007, N. Tayem and M. Naraghi-Pour also used this matrix to quickly orient the relative radiation sources applied to the ULA antenna array [76]. The outstanding advantage of this method is that it allows the orientation of highly correlated radiation sources. According to this method, the data are rearranged in a Hermitian Toeplitz format to extend the signal space size. This method is suitable for real-time applications as it uses only a few observed signal samples. However, both works mentioned above only mention orientation in the azimuth plane.

In 2011, author Hongshu Liao presented an orientation method called 2D-ESPRIT [45]. In his research, the author uses two ULA antennas arranged in parallel on the same plane. Here, the author uses the immutable displacement property of the sub-signal array and builds the covariance matrix based on those sub-signal arrays.

The advantage of this method is that it allows the simultaneous orientation of many radiation sources with quite high accuracy. In the same year, Jianfeng Chen also introduced a quick orientation method using cross-correlation matrices [12]. In essence, this is an innovative PM algorithm applied to the ULA antenna. This method can work under nonlinear interference conditions. The biggest limitation to the two methods above is the need to use multiple signal patterns.

In 2013, an improved spatial smoothing method was proposed by Yuexian Wang and Matthew Trinkl to orient the correlated radiation sources [81]. The data matrix was reconstructed based on the symmetry of the UCA antenna array to break the signal correlation. Theoretical analysis and simulation results show that this method has quite good accuracy even when the SNR is small. However, this method has quite a large computational complexity.

In addition, in 2013, the authors Yasser Albagory and Amira Ashour proposed a 2D orientation method using the MUSIC algorithm applied to the ULA-UCA antenna array (consisting of a ULA antenna array placed vertically at the center of a UCA antenna. [9]. However, this method has a rather large computational complexity and is only suitable for the orientation of uncorrelated radiation sources.

In 2017, Yang-Yang Dong presented a 2D orientation method using an L-shaped antenna array [88]. This method uses the conjugate vector conjugate relationship for the ULA antenna array to simultaneously increase the array aperture and number of signal patterns used. With M elements per ULA antenna, this method can direct 2 (M-1) radiation sources. To reduce the computational complexity, the proposed solution is the sequential orientation (forward angle, back azimuth) based on Rayleigh ratio equation. Then the elevation angle and azimuth are combined into the corresponding pairs.

In 2018, author Y. Khmou proposed an improved PM algorithm applied to the UCA antenna array in a radar system that monitors fixed narrow band radiation sources [40]. This method is suitable for both Gaussian white noise and color noise with symmetrical Toeplitz form of covariance matrix. Although this method allows for 2D orientation, the calculation time is still quite large because the entire elevation scan must be performed during the determination of the azimuth.

In addition to the research trend in the world, some Vietnamese researchers are also very interested in this field, in which there are some prominent research groups such as Hanoi University of Technology, Hanoi National University. , Electricity University, Military Science and Technology Institute, Military Technical Academy ..., specifically:

In 2012, several models and data synthesis algorithms for multi-signal directional systems with ULA and UCA antennas were proposed in [2]. In addition, the author also recommends a wide band direction model for these antennas.

In 2012, the algorithm for estimating the signal parameters in radio communication was presented in [6]. The two algorithms proposed by the author include: CFO, FDOA parameter estimation algorithm and the improved algorithm of the simultaneous estimation of the signal parameters such as: DOA, Doppler frequency, parallel transmission delay and determination. 2D direction using space smoothing technique.

In 2013, Asym-AWPC architecture was proposed to solve the problem of spectrum repeater using AWPC antenna combined with MUSIC algorithm [7]. In addition, the author also proposed CS algorithm for Asym-AWPC orientation system operating in the environment of correlated radiation sources.

In 2015, the application orientation for single-channel and multi-channel system was presented in [1]. With the single-channel orientation system, the innovative phase-locking (PLL - DOA) orientation method can reduce computational complexity to increase processing speed as well as overcome the confusing disadvantages of the lock ring. phase when there are two similar radiation sources arriving at the antenna array at the same time. With the multi-channel directional system, the TFBMP algorithm applied to the ULA and UCA antennas is able to direct radiation sources relative to only one signal pattern. Besides, the method of simultaneously determining DOA and TOA parameters using TFBMP algorithm applied to the ULA antenna is also proposed by the author.

Some typical oriented products that have been applied in practice include:

- PSI-1850 shortwave system: this is a shortwave direction system manufactured by Thompson (France) with a high level of automation, introduced in the mid-1990s. interference principle, integrated with GPS, capable of storing results and showing results of orientation on a map.

DDP-5900 ultra-short wave direction system: This is a directional system made by Doppler System (USA). The system works based on the Doppler pseudo principle.

- WD-3000 microwave directional system: This is a system manufactured by Winradio (Canada) based on the Doppler pseudo principle.

- Short wave direction system DFR-1000B: This system is manufactured by RDF Products (USA), operating on the Watson-Watt principle.

- DDF-195 radio navigation system: This is a system built by Rohde & Schwarz (Germany), operating on the basis of the Watson-Watt principle and correlative communication.

 About the problem of locating radiation sources:

Besides the research and development of orientation methods, the problem of locating radiation sources is also getting more and more attention. Basically, the positioning problem is the next development step based on the orientation problem. The positioning problem will be one of the top priorities in application development. In civilian, typical applications such as: rescue and rescue, first aid locator and ALI automatic location recognition. In the military field, early detection and target positioning are crucial in remote combat. The positioning methods can be classified as follows [2]:

Interference method: Determining target coordinates based on measuring angles towards the target of at least two receiving stations arranged a distance in space.

- Distance difference method: Determine target coordinates based on measuring the distance from radiation source to receiving stations.

- Angle method - distance difference: Determine the target coordinates based on measuring the angles towards the radiation source and the difference from the radiation source to the receiving stations.

There are also some other methods such as carrier phase (CP), signal strength (RSSI).

Common methods based on math to solve positioning problems such as: AOA (intersection of lines), TOA (intersection of circles), and TDOA (intersection of hyperbolic lines)). For these methods, when the lines or curves do not intersect at a point due to the effect of the noise, the calculation becomes difficult.

In 2015, author Yue Wang presented the AOA positioning method with many advantages such as: Improved accuracy when there are errors in the location of receivers, reducing the total estimated location deviation due to interference sources. and receiver position errors when using linear pseudo-equation [80]. According to this method, at least three receivers are required to direct the radiation source in a linear signal medium.

The positioning method based on signal reflection phenomenon was proposed by S. Haidari in 2016 [29]. In essence, this method estimates the distance from the receiver to the source of the radiation and the angle of reflection according to the predicted RSSI data sample. This method is highly theoretical and can only be applied under conditions of a priori information about known radiation sources (frequency, transmit power, transmission model).

Through researching the published works shows:

- Accuracy, resolution and computational complexity issues: Algorithms such as MLM, AAR, TNA, MEM, MUSIC, ESPRIT, Root-MUSIC, TLS-ESPRIT

... and methods using spatial smoothing in the orientation of correlated radiation sources are not suitable for real-time applications due to the large computational complexity and the use of multiple signal patterns. The improved PM algorithm, although improving the accuracy, reducing computational complexity, is only applicable to a few antennas and also requires multiple signal patterns. The Matrix pencil and CS algorithm, although allowing the orientation with only one signal sample, needed to satisfy a certain number of conditions in solving the solving problem. The MUSIC algorithm applied to the ULA-UCA antenna array in the 2D orientation of the uncorrelated radiation sources has somewhat reduced the computation time, but the computation complexity is still quite large due to the implementation of the racks. private value.

- The problem of the influence of nonlinear noise, color noise and a priori information uncertainty in the number of radiation sources: Most studies consider only under conditions affected by Gaussian white noise and have known prior information. solutions on the number of radiation sources. Although there have been a number of methods considering nonlinear noise and color noise, the results have not been as expected. The method of using quaternary semi-invariant matrices under a priori information uncertainty on the number of radiation sources has been mentioned, but only in the 1D orientation.

- The problem of using directional results in locating radiation sources: The positioning problem is mainly considered in the unobstructed topography condition between radiation source and receiver. The positioning method using the reflected signal based on the RSSI signal strength measurement and the transmission line model has been presented, but the results depend much on the assumed conditions of signal frequency, estimated distance. as well as the structure of the reflector. Solving the positioning problem using orientation results and geographic a priori information has not been studied much.

On the basis of the above conclusions, the study will focus on solving specific tasks as follows:

- The research proposes the orientation solution with high accuracy, low computational complexity, and capable of operating in small SNR conditions.

- The study proposes a directional solution in conditions affected by some color noise and solves the 2D orientation problem under a priori information uncertainty in the number of radiation sources.

- Research to propose positioning solutions with high practical application based on orientation results.

As a basis for the proposals, the next part of the study will study some general theories such as: General orientation problem, orientation algorithms and typical radiation source locating methods.

3. Research method

Perform theoretical research, signal models, apply mathematical tools, simulate computation and evaluate on computers. Mathematical theories and tools used mainly in research include: The theory of antennas, radio transmissions; optimal array handling; theory of space-time processing; radio statistics theory; linear algebra; analytic geometry; functional analysis; Matlab simulation tools

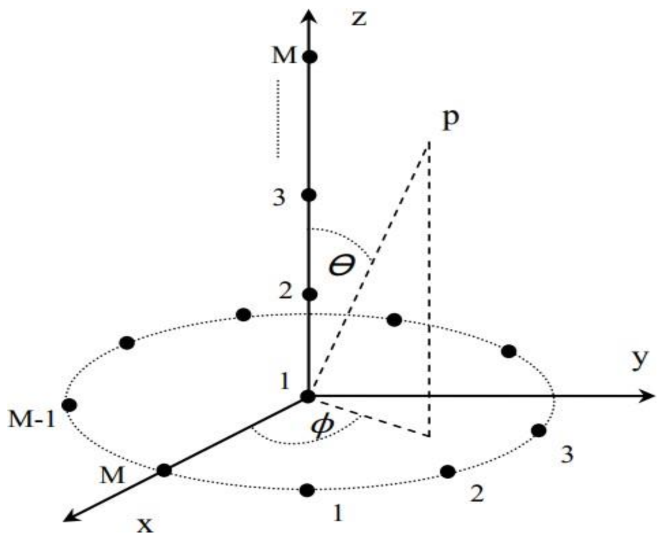

Figure 1: Model of the ULA-UCA antenna array [9]

The ULA-UCA antenna model shown in Figure 2.1 is a combination of the ULA and UCA antenna array, in which the ULA antenna array is placed vertically at the center of the UCA antenna. In practice, the number of elements per selectable antenna array differs. However, the number of antenna elements is decisive to the maximum possible direction of multiple radiation sources simultaneously. Therefore, the number of antenna elements ULA and UCA are generally equal (consisting of M elements). Assume that the distance between the elements (d) on both antennas is the same half wavelength (λ).

The direction model applicable to the ULA-UCA antenna array is shown in Figure 2.2. The principle of operation consists of two phases: Stage one is responsible for processing the signal to the ULA antenna to find the elevation (θi) angles, the second stage is to determine the azimuth (ϕi) angles with the antenna array. The corresponding UCA elevation angle was obtained from stage one. According to this solution, the azimuth angle is determined on the plane limit of the obtained elevation angle instead of searching for the entire elevation angle in the range from 0 to 180o. This does not affect the calculation in the 2D orientation methods [9].

4. Result

Table 1. Orientation resolution of proposed solution with ULA-UCA antenna under Gaussian white noise

SNR					
	$\Delta\theta$	**θ_1**	**θ_2**	**θ_1'**	**θ_2'**
-5dB	15	25	40	25,28	40,01
0dB	11	25	36	25,52	35,59
5dB	8	25	33	25,3	32,91
10dB	6	25	31	25,06	30,97
	$\Delta\phi$	**ϕ_1**	**ϕ_2**	**ϕ_1'**	**ϕ_2'**
-5dB	10	70	80	69,88	79,98

0dB	5	70	75	70,04	75,97
5dB	3	70	73	70	73
10dB	2	70	72	70,01	71,99

Table 2. Recommended solution orientation resolution for ULA-UCA antenna under nonlinear interference conditions

SNR					
	$\Delta\theta$	θ_1	θ_2	θ_1'	θ_2'
-5dB	31	25	56	24,02	56,49
0dB	26	25	51	24,09	51,49
5dB	10	25	35	24,54	35,34
10dB	7	25	32	24,92	32,06
	$\Delta\phi$	ϕ_1	ϕ_2	ϕ_1'	ϕ_2'
-5dB	35	70	105	70,06	105
0dB	34	70	104	70,96	103,68
5dB	13	70	83	69,05	83,14
10dB	2	70	72	69,38	72,26

Using multiple signal patterns will reduce the processing speed of the algorithm as well as the operating speed of the system. Therefore, depending on the purpose of different uses, we choose the appropriate number of samples to be used to ensure the balance between accuracy and processing speed.

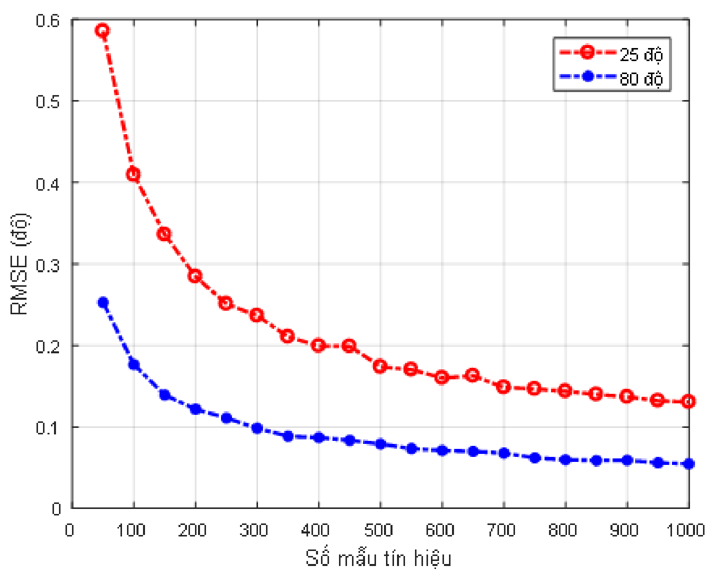

Figure 2. Dependence of RMSE angle between two radiation sources (25o, 70o) and (80o, 310o) by number of signal samples

The new solution uses an improved PM algorithm to reduce computational complexity but still ensures high accuracy and is suitable for applications with small SNRs. Firstly; it is proposed to apply the improved PM algorithm combined with the solution to limit the elevation-plane angle to azimuth based on the model of the antenna array ULA-UCA. The obtained simulation results show that the proposed solution has shown the superiority in computation time while still ensuring the accuracy and resolution equivalent to the MUSIC algorithm in white noise conditions. Gaussian. Furthermore, in the condition of nonlinear noise and small SNR, the proposed solution has higher accuracy and resolution compared to the traditional MUSIC and PM algorithms. The second is to propose an improved PM algorithm in combination with a Toeplitz signal vector construction solution based on the ULA antenna model. This proposed solution is capable of directing highly correlated radiation sources. The outstanding advantage of this solution is that it only requires one signal sample, but still has high accuracy and resolution even when the SNR is small. From there, the oriented systems will reduce memory capacity, volume and computation time.

5. Conclusion

The study has studied the theoretical basis, the radio radiation source direction algorithm and some structural models of the antenna array on a linear algebraic basis. With the aim of improving the quality of direction of radio radiation sources, research has studied a number of solutions to solve two basic problems:

Accuracy, resolution and computational complexity: The study has studied using an improved PM algorithm applied to the structure of the ULA- UCA and ULA antenna. The results showed that this combination brings the advantages of: low computational complexity, high accuracy even when the SNR is small. Minimum number of elements per antenna array is M = 2p + 2. With ULA-UCA structure with M

= 10, the solution uses the improved PM algorithm capable of successfully determining two incident wave directions with only 50 signal samples and SNR = -10dB. The simulation has proven that this solution improves accuracy and resolution compared to using traditional PM algorithm and MUSIC (especially in the case of nonlinear noise). With the ULA antenna array, the reconstruction of the signal vector in Toeplitz form before applying the improved PM algorithm allows the direction of the radiation sources relative to only one signal sample. Compared with algorithm ESPRIT, Matrix Pencil and TLS, this solution has better accuracy.

The problem of the effect of color noise and a priori information uncertainty in the number of radiation sources: Research has studied the effect of color noise, built a signal model based on L-shaped and ULA antennas. -ULA orthogonal with symmetrical phase center. With the L-shaped antenna array, the covariance matrix is reconstructed based on the symmetry of the color noise in Toeplitz form before using the PM algorithm. This solution is able to orient the correlated radiation sources in pairs under very small SNR conditions (-15dB) and only need to use a few signal samples (10 samples). With the smaller SNR, this solution still has high accuracy and resolution because the noise content has been completely eliminated from the signal power spectrum. Meanwhile, the use of orthogonal ULA-ULA antennas with symmetrical phase center coupled with signal modeling based on a quaternary non-invariant matrix allowed 2D direction of correlated radiation sources in the Event is affected by correlated color noise. Compared with the FBSS method, this solution does not need a priori information on the number of radio radiation sources.

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