UDC 621.396.96
https://doi.org/10.47533/2024.1606-146X.45

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ALGORITHMIC IMPROVEMENT OF THE HIGH-SPEED DIGITAL SPECTRAL-CORRELATIVE RADIOLOCATION METHOD

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The algorithmic improvement of the high-speed digital spectral-correlative radiolocation method represents an innovative project that influences the development of new technologies. This work aims to enhance the precision and reliability of receiver systems through accurate signal direction, presenting new methodologies for addressing issues in the radiolocation field by analyzing spectral components of signals and their correlational relationships.

Applying these algorithmic enhancements allows for significant improvements in the speed and accuracy of radiolocation processes. This benefits the efficiency of both military and civil communication systems, paving the way for future developments in radioelectronics and contributing to technological innovations.

Keywords: *digital radiolocation, spectral-correlative analysis, algorithmic improvement, signal processing, mathematical models.*

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ЖОҒАРЫ ЖЫЛДАМДЫҚТЫ ЦИФРЛЫҚ СПЕКТРЛІК-КОРРЕЛЯЦИЯЛЫҚ РАДИОЛОКАЦИЯ ӘДІСІН АЛГОРИТМДІК ЖЕТІЛДІРУ

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Жоғары жылдамдықты цифрлық спектрлік-корреляциялық радиолокация әдісін алгоритмдік жетілдіру жаңа технологиялардың дамуына әсер ететін инновациялық жоба болып табылады. Бұл жұмыстың мақсаты сигналдардың спектрлік компоненттерін және олардың корреляциялық байланыстарын талдау арқылы радиолокация саласындағы мәселелерді шешудің жаңа әдістемелерін ұсына отырып, сигналдың дәл бағыты арқылы қабылдау жүйелерінің дәлдігі мен сенімділігін арттыру болып табылады. Осы алгоритмдік жетілдірулерді қолдану радиолокациялық процестердің жылдамдығы мен дәлдігін едәуір арттыруға мүмкіндік береді. Бұл әскери және азаматтық байланыс жүйелерінің тиімділігін арттырады, радиоэлектрониканың болашақ дамуына жол ашады және технологиялық инновацияларға ықпал етеді.

Түйін сөздер: *сандық радиолокация, спектрлік корреляциялық талдау, алгоритмдік жетілдіру, сигналдарды өңдеу, математикалық модельдер.*

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АЛГОРИТМИЧЕСКОЕ СОВЕРШЕНСТВОВАНИЕ МЕТОДА ВЫСОКОСКОРОСТНОЙ ЦИФРОВОЙ СПЕКТРАЛЬНО-КОРРЕЛЯЦИОННОЙ РАДИОЛОКАЦИИ

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Алгоритмическое усовершенствование метода высокоскоростной цифровой спектрально-корреляционной радиолокации представляет собой инновационный проект, который влияет на разработку новых технологий. Целью данной работы является повышение точности и надежности приемных систем за счет точного направления сигнала, представляя новые методологии решения проблем в области радиолокации путем анализа спектральных компонентов сигналов и их корреляционных связей.

Применение этих алгоритмических усовершенствований позволяет значительно повысить скорость и точность процессов радиолокации. Это повышает эффективность как военных, так и гражданских систем связи, прокладывая путь для будущих разработок в области радиоэлектроники и способствуя технологическим инновациям.

Ключевые слова: *цифровая радиолокация, спектрально-корреляционный анализ, алгоритмическое усовершенствование, обработка сигналов, математические модели.*

1. Introduction. The algorithmic improvement of the high-speed digital spectral-correlative radiolocation method marks a step into a new phase of technological advancement, leading to significant changes in solving precise issues within radioelectronics and communications [1]. The primary goal of this technology is to enhance data accuracy and signal quality by determining the direction of radio signals emitted from specific sources.

In recent years, traditional methodologies, particularly in processing low-frequency signals, have encountered their limitations [2]. New developments and research, notably through spectral-correlative analysis, offer the potential to refine these aspects, thereby increasing efficiency and reducing signal processing times [3].

When focusing on the algorithmic aspect of this research, the main goal is to create new mathematical models and apply them in software development. This ensures a synergy between speed and accuracy aspects, which can be utilized in radioelectronic systems of any configuration [3,4].

During the course of this scientific work, we will explore ways to enhance the performance of these algorithms and also attempt to define their practical applications. These improved algorithms could find applications in areas such as security, monitoring, and protection, potentially enhancing their potential and unlocking new technological opportunities.

2. Materials and Methods. The key feature of the algorithmic improvement of the high-speed digital spectral-correlative radiolocation method is as follows (Figure 1) [1,5]:

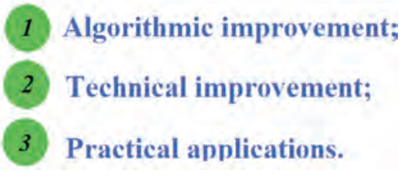


Figure 1 – Properties of Algorithmic Improvements in High-Speed Digital Spectral-Correlative Radiolocation Methods

Herein:

1. The primary goal of algorithmic improvement is to increase accuracy and speed. Similarly, this method is aimed at enhancing the precision and speed of algorithms. The digital spectral-correlative radiolocation method reduces delays in signal reception and processing, thereby improving data accuracy;

2. Technical enhancements - utilize complex algorithms. The updated algorithms include complex mathematical models and statistical methods, which help achieve high accuracy in signal analysis. They also enhance the ability to operate in noisy environments. Algorithms are optimized to reduce the effects of noise and other disturbances, which allows for effective direction of radio signals;

3. Practical applications - have particular use in defense and intelligence directions. These enhancements are very useful for military and intelligence applications because they allow for quick and accurate detection of hostile signals. They are also particularly useful in aviation and space navigation, where improvements in algorithms lead to increased accuracy of signals in aviation and space navigation systems. These enhancements significantly improve the quality of radiolocation and expand its applicability across various sectors. The main features and shortcomings of the algorithmic improvements in the high-speed digital spectral-correlative radiolocation method are as follows [6]: Features:

➢ High accuracy - the algorithms used in the digital spectral-correlative method achieve very high precision in determining the direction of radio signals [7]. This method reduces the impact of surrounding noise and allows for accurate identification of the actual signal source;

➢ Speed - the processing speed of signals through digital processing is increased, which is crucial for real-time operation [8];

➢ Expanded scope of application - this method can be used in military, aerospace, and telecommunications fields, which broadens the range of its application. Shortcomings:

➢ Complexity - the digital spectral-correlative method is very complex, which increases the cost of equipment and complicates its production and maintenance [9];

➢ High resource requirements - processing high-precision signals requires substantial computational resources, which in turn increases operational costs [1,8];

➢ Technological limitations - there might be situations where it does not operate effectively in all environments and conditions, for example, in extremely noisy environments or at very low frequencies [5,9]. These are the main characteristics and shortcomings of this scientific research work. These are important aspects for the scope of research conducted in this field and its applicability to production.

3. Results and Discussions. The main goal of the study is to enhance the efficiency and speed of radiolocation systems. Such systems are typically used for military and civilian purposes, for example, to determine the positions of aircraft and ships. The main methodologies and scientific results used in this study are presented below (Figure 2).

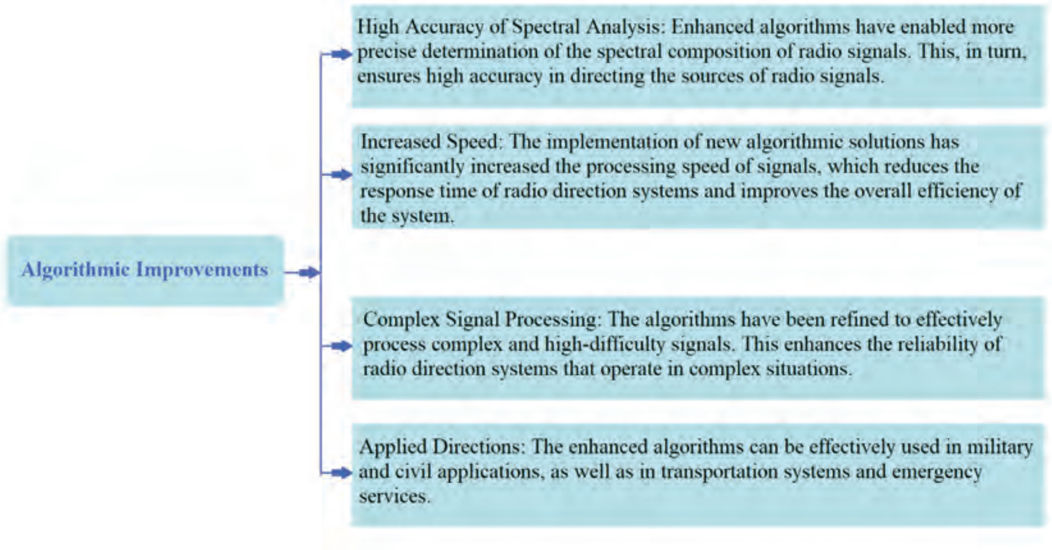


Figure 2 – Algorithmic Improvements in Digital Spectral-Correlative Radiolocation Methods

This article presents research results as shown in Figure 2. The results obtained during the study demonstrated significant improvements in the accuracy and speed of radiolocation systems. The enhancements in algorithms reduced the error rate of the systems and improved their response time. This study represents a significant progress in radiolocation technology and has great future potential. Future directions include expanding the scope of algorithms for further research and testing them in various radiolocation scenarios. Additionally, exploring the application of new algorithmic solutions in both military and civilian technologies is considered important.

3.1 Theoretical Basis of the Correlation Function Used for Directing the Source of Radio Signals. The calculation of the correlation function of a signal - the correlation function $R_{xy}(\tau)$ in a radiolocation system between two signals $x(t)$ and $y(t)$ is defined as follows:

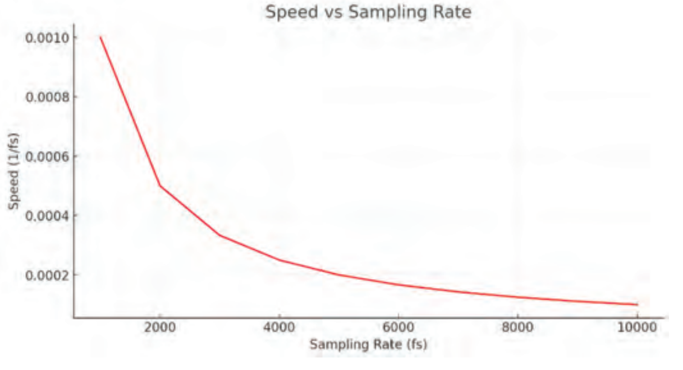
$$R_{xy}(\tau) = E[x(t) \cdot y(t + \tau)] \quad (1)$$

where $E[x(t) \cdot y(t + \tau)]$ – represents the expected mathematical value, and τ is the delay time.

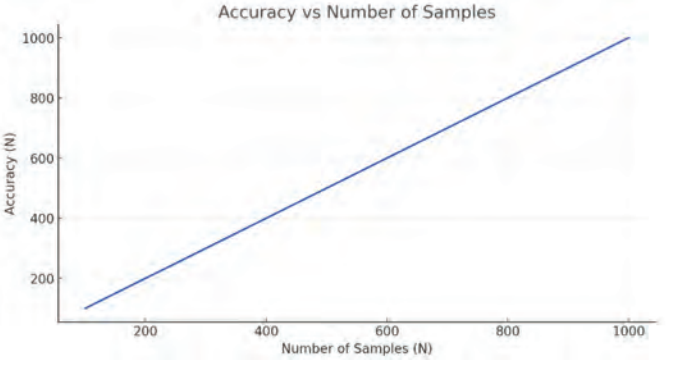
Transitioning from correlation to spectrum – using the data obtained through the correlation function, we apply the Fourier transform to find the spectral composition of the signal:

$$S_{xy}(f) = \int_{-\infty}^{\infty} R_{xy}(\tau) e^{-j2\pi f \tau} d\tau \qquad (2)$$

The Relationship between Speed and Accuracy – we determine the optimal parameters of the algorithm to ensure both speed and accuracy. For example, let the length of the signal in discrete time be N and the sampling frequency be f_s. Using these parameters, we can evaluate the processing speed and accuracy.



a) The relationship between speed and sampling frequency. As the sampling frequency f_s increases, the speed increases. The change in speed is represented as $1/f_s$, which is the inverse of the sampling time.



b) The relationship between accuracy and the number of samples. As the number of samples N increases, accuracy also increases. This indicates that a higher number of samples improves the spectral resolution of the signal.

Figure 3 – Graph illustrating changes for evaluating process speed and accuracy

Let's consider the process of using the Fourier transform to determine the spectral composition of a signal from its correlation function. For this purpose, we model the autocorrelation function, then transform this function using Fourier transform to obtain the spectral composition. Let's use a simple cosine signal for this. Calculation of the autocorrelation function:

Let the signal be $x(t)=A\cos(2\pi f_0 t)$, where A is the amplitude and f_0 is the fundamental frequency. The autocorrelation function of this signal is:

$$R_{xx}(\tau) = \frac{A^2}{2}\cos(2\pi f_0 \tau) \tag{3}$$

Applying the Fourier transform. The Fourier transform of the autocorrelation function reveals the spectral composition. The Fourier transform from equation (2) can be written as follows:

$$S(f) = \int_{-\infty}^{\infty} R_{xx}(\tau) e^{-j2\pi f\tau} d\tau \tag{4}$$

Now, let's implement these processes using a Python program and visualize the results. First, in the Python program, let's model the signal and its autocorrelation function, then use the Fourier transform to plot the spectrum. Let’s execute the code.

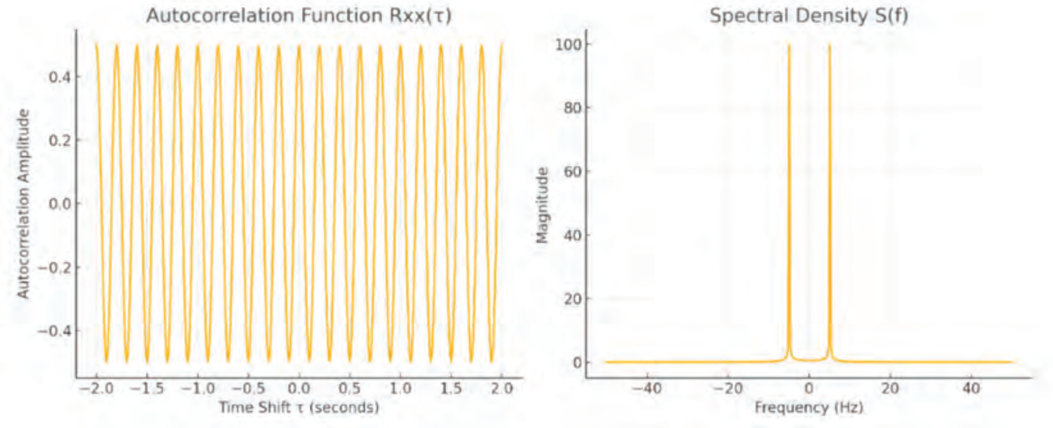


Figure 4 – General Representation of the Autocorrelation Function

This figure shows the autocorrelation function $Rxx(\tau)$, which is in the form of a cosine and related to the fundamental frequency f_0 of the signal. The autocorrelation demonstrates cosine oscillations dependent on the time delay. The spectral density $S(f)$ - this graph shows the spectral composition obtained from the Fourier transform. There are two peaks near the frequency f_0, illustrating the spectral representation of the signal’s cosine form. These graphs help us understand what the signal and its autocorrelation look like, and how the spectral composition of that signal appears.

3.2 Discussion of Scientific Research. The scientific research encompasses significant innovations in radiolocation technology and its algorithmic aspects. To analyze this topic, it’s necessary to highlight the following key aspects:

1. Essence of Digital Spectral-Correlative Radiolocation Method - The digital spectral-correlative radiolocation method uses spectral analysis and correlation measurements to determine the sources of radio signals. This method is employed to identify the spatial direction of radio signals and also assists in pinpointing the location of the signal origin;

2. Algorithmic Improvements - Typically, algorithmic improvements involve increasing computational speed, enhancing accuracy, and expanding capabilities. Such enhancements allow for faster and more precise processing of signals, thus increasing the efficiency of radiolocation systems;

3. Technical Applications - These improvements are crucial in both military and civilian applications. For example, in the military, radiolocation systems are used to detect enemy radio sources during combat operations. In civilian sectors, this technology is beneficial in aviation, maritime navigation, and rescue operations;

4. Future Directions - In the future, enhancements to these technologies will be linked to the development of new sensors and algorithms. Additionally, the integration of artificial intelligence and machine learning methods will further refine radiolocation techniques.

The research and improvements in this topic help to understand how technological progress is being implemented in the field of radiolocation.

The authors express their gratitude to the leadership of project **BR20280990** “Devising and developing methods for solving fundamental problems of fluid and gas mechanics, new deformable bodies, reliability and energy efficiency of machines, mechanisms, robotics” for their assistance in conducting this research, as well as writing this article.

Conclusion. The development of modern radio electronics and radiolocation systems is rapidly accelerating each year, with new technological solutions and algorithmic improvements being introduced. In this research, we analyzed innovations in the algorithmic improvement of the high-speed digital spectral-correlative radiolocation method and their applications in radiolocation systems.

Our studies have found that algorithmic improvements significantly enhance the speed and accuracy of processing radio signals. These improvements allow for precise identification of the spectral composition of radio signals and highly accurate direction-finding of their sources. As a result, the efficiency of radiolocation systems across various applications has increased. Additionally, by enhancing the speed and efficiency of algorithms, we have managed to reduce errors in locating radio sources in both military and civilian applications. These enhancements are particularly important in military operations and in search and rescue operations during disasters.

The conducted research and the results obtained demonstrate significant advancements in the development of radiolocation systems and suggest a promising future for this field. Moving forward, efforts will continue to further develop these technologies and introduce new algorithmic solutions aimed at enhancing the efficiency of radiolocation systems and expanding their range of applications.

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