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FRACTALS REVOLUTIONIZE RADAR BY UNVEILING SUPERIOR SIGNAL PROCESSING TECHNIQUES

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ABSTRACT

General Background: Fractal radiophysics and fractal radio electronics represent advanced fields focusing on the creation and development of innovative radio systems. **Specific Background:** The integration of fractals, textures, fractional operators, and nonlinear dynamics into radiophysics and radiolocation is an emerging area of study with substantial potential. **Knowledge Gap:** Despite significant advancements, there remain critical gaps in understanding the application of these elements to improve radiophysics and radar signal processing. **Aims:** This study aims to bridge these gaps by employing long-term natural experiments, statistical analyses, and new information technologies to enhance the identification and classification of land covers and to develop advanced radar maps. **Results:** The findings demonstrate the effectiveness of fractal methods in improving the accuracy of radar signal processing and land cover classification, with fractal-based approaches outperforming traditional methods. The study also introduces novel textural techniques for identifying objects in optical and radar images, even under low signal-to-background conditions. Additionally, the feasibility of generating synthetic optical and radar images through stochastic autoregressive synthesis has been theoretically justified and experimentally validated, achieving a physical accuracy of 90%. **Novelty:** This research is the first to explore the combined textural and spatial spectral-correlation features of optical and radar images for land cover classification, highlighting the superiority of fractal-based approaches. **Implications:** The results provide a robust theoretical foundation for the practical application of fractal radiolocation and radio electronics, offering new directions for the development of advanced radar technologies and information processing methods, thus contributing to the evolution of modern radiophysics and electronic systems.

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INTRODUCTION

The paper examines the primary areas in which textures, fractals, fractional operators, and methods of nonlinear dynamics are applied to address the fundamental difficulties in the field of radio physics. The combination of radiolocation with a diverse array of radio engineering techniques is utilized to develop novel information technologies. The investigation is being carried out as part of the research area "Fractal Radio physics and Fractal Radio electronics: Designing Fractal Radio Systems", which was initiated and developed by the author at the V. A. Kotelnikov IRTE of the Russian Academy of Sciences from 1979 to the present day [1-50].

Key findings Through collaborative long-term natural experiments with prominent industry research institutes and design departments of the USSR and Russia, we conducted a statistical analysis of extensive new data on the spatiotemporal dispersion characteristics of land covers within the MMW and SHF ranges. The analysis considered the changes in seasons and angles, as well as different weather conditions, to determine the limits of radar contrasts. It also examined the distribution patterns of specific radar cross sections, spectral width, time, and fluctuation correlation interval of reflected signals within the millimeter wave range. Additionally, it studied the structure of reflected pulse signals, taking into account the terrain characteristics, to develop different imaging systems. A theory on the scattering of millimeter radio signals by chaotic coverings has been formulated. The study utilized the initial implementation of stochastic backscattered fields and frequency coherence functions in relation to the antenna directivity diagram and the correlation of unevenness slopes. The findings of this theory enable the identification of the coherence zones of space-time radio channels with varying parameters. This information is crucial for selecting the optimal bandwidth of the sounding signal, frequency spacing in multi-frequency systems, and values of the complex sounding signal base. It also helps determine the reflected signal characteristics, generalized uncertainty functions, potential accuracy of aircraft overflight height estimates, and characteristic dimension of unevenness. The creation of reference digital radar maps involved the utilization of both theoretical and experimental findings.

A novel class of informative characteristics has been proposed, which is based on the intricate patterns found in the reflected radar signals of millimeter range radio waves. It facilitates the enhancement of land cover identification

METHODS

This study is the first to examine the combined textural and spatial spectral-correlation features of optical and radar pictures of real land covers. The images were analyzed using clustering techniques to identify the most informative features for specific texture classes. The existence domain of textural features in radar pictures inside the MMW range is entirely governed by the equivalent domains of optical image characteristics, as proven. The conducted trials showcased the efficacy and universality of the suggested methodology in the field of land cover categorization, specifically in the integration of optical and millimeter wave pictures. Integrating photos enhances the effectiveness of detecting, identifying, and classifying objects by utilizing a comprehensive set of useful and reliable attributes. The outcome of image processing consists of intricate digital radar maps. These maps allow for the presentation of radar information in a format that is appropriate for the subsequent utilization in aircraft radio navigation and the recognition of different types of ground objects.

The author has introduced novel textural techniques to identify different objects and their outlines in actual optical and radar images of the ground surface, even when the signal-to-background ratio is low. The link between the dimensions of the item and the studied segment.

An investigation has been conducted on the use of optical and radar images to detect various types of land covers. The study focuses on achieving optimal detection. The feasibility of generating optical and radar images of land covers using stochastic autoregressive synthesis, along with the transformation of intensity bar graphs, has been theoretically justified and experimentally validated. The appropriate dimensions of the intensity domain and the order of the autoregressive series required for accurate picture synthesis have been established. As the correlation order increases, the range of values used to determine the textural aspects of the synthesized images becomes smaller. The comparison of specific sections of the original optical or radar image with a synthetic reference standard reveals that the resulting two-dimensional binary field of cross-correlation coefficients accurately identifies the precise location of the object in the original image. It enables the acquisition of a map and understanding of the movement patterns of the observed object. Through the utilization of different combination algorithms, such as classical correlation, the method of pair functions, and the method of absolute difference, it has been determined that the stochastic autoregressive synthesis achieves a physical accuracy of 90%.

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RESULTS AND DISCUSSION

Based on the aforementioned radio physical research, a systematic strategy has been designed and executed to provide an axiomatic information model of radar maps for non-uniform terrain. A comprehensive radio physical model has been created to generate radar maps of uneven terrain. It encompasses both techniques of probabilistic autoregressive picture generation and the data on the radar cross- section (RCS) characteristics of land coverings. The specific RCS of the ground surface has been determined by its characteristic gradation number. An algorithm is created to synthesize radio range contour and halftone radar maps of non-uniform terrain based on the analysis of the system architecture for getting the reference standard. The destruction of the correlation maximum occurs when examining a contour radar map of the landscape with a wavelength of 8.6 mm and a relative turn angle between 50 and 70 degrees. For a halftone radar map, the destruction occurs at an angle between 140 and 170 degrees. Subsequently, the fractal parameters were initially incorporated into the comprehensive radio physical model to create radar maps of heterogeneous terrain. This fact has augmented the informational capacity of the synthesis.

A prediction was made about the presence of a peculiar attractor that governs the radar scattering from vegetation coverings. Subsequently, the impact was empirically observed at a frequency of 2.2 mm (2002). The results obtained have validated the theoretical concepts about the presence of chaos in a dynamic system that characterizes the dispersion of electromagnetic waves by vegetation coverings. By reconstructing the attractor, we were able to calculate its fractal size D, maximal Lyapunov exponent, embedding dimension, and prediction interval (time). The unique properties of the unfamiliar attractor served as the foundation for a novel radar scattering model of MMW by vegetation cover. This model was developed using the principles of dynamical systems and stable distributions, which diverge from the traditional Gaussian model. It has been demonstrated that the time interval for forecasting the intensity of the reflected radar signal is roughly ten times longer than the classical correlation time. This enabled the incorporation of a new crucial feature, known as the prediction interval, into the theory of radiolocation. This expansion encompassed the methods and electronic components utilized in radio locators.

A solid empirical validation of the practical implementation of fractal techniques in contemporary fields of radio physics, radio electronics, and information control systems has been established. In the mid-1980s, a coherent compact digital solid- state radar (DSR) operating model was developed. This radar, based on parametrons, had a sounding wavelength of 8.6 mm and a complex signal base greater than 106. It was designed in collaboration with the "Almaz" Central Design Bureau and was capable of processing sub-noise signals on a carrier frequency. The energy potential of the DSR increased by 50 dB after optimal processing. Subsequently, a Dual Sounding Radiometer (DSR) was developed, capable of operating at two specific frequencies within the Millimeter Wave (MMW) and Super High Frequency (SHF) ranges. This DSR was equipped with a pioneering fractal slot antenna, marking the first of its kind in the Soviet Union. The Radon transformation was employed for image synthesis. The development of fractal modulation and fractal signals occurred in 1997. The author introduced H-signals, which were included. The effectiveness and accuracy of applying the theory of fractional measurement and scaling ratios (for textures and fractals) in detecting and identifying one-dimensional and multidimensional radar signals from low-contrast targets against intense non-Gaussian interference of various types has been discovered and demonstrated for the first time. Therefore, that was essentially innovative radio technology

CONCLUSION

Fundamental Finding: This study highlights the innovative integration of textures, fractals, fractional operators, and nonlinear dynamics into radiophysics, significantly enhancing land cover identification, classification, and radar signal processing. **Implication:** The results provide a strong theoretical foundation for practical applications in fractal radiolocation and radio electronics, potentially revolutionizing current methodologies and guiding future technological advancements in these fields. **Limitation:** However, the study primarily focuses on specific applications within radiophysics, leaving broader implications in other areas of radio engineering unexplored. **Further Research:** Future investigations should expand the exploration of fractal methods into other domains of radio engineering and examine the wider applications of fractal technologies across diverse scientific and industrial sectors.

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