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# Prospects for the Development of Special-Purpose Optoelectronic Systems Using Stochastic-Deterministic Optical Signal Processing Methods

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*Abstract* – **The study is devoted to the analysis of theoretical aspects of methods for constructing optoelectronic systems, identifying internal contradictions in the process of their improvement, and exploring promising directions for the development of models of optical signal reception and processing. The relevance of the problem of registering weak and low-contrast objects under a wide range of illumination conditions and against strong interference is demonstrated. Possible directions for system modernization are considered: lowering sensitivity thresholds, matching the dynamic range, and improving algorithms for statistical signal processing. The theoretical foundation of the proposed approaches is a stochastic-deterministic description of optical radiation as a random photon stream, which takes into account wave, corpuscular, and quantum-mechanical properties of light, as well as statistical models based on non-Gaussian isotropic distributions. The use of modern methods of spectral and spatial filtering, nonlinear algorithms, and digital technologies makes it possible to significantly enhance sensitivity, resolution, and operating range of the systems. The obtained results provide a basis for synthesizing optimal signal detection algorithms and can be applied in the development of new and modernization of existing optoelectronic devices, ensuring improved technical characteristics and competitiveness.**

***Keywords* – optoelectronic systems; signal reception and processing; stochastic-deterministic models; Non-Gaussian isotropic distributions**

The purpose of this work is to analyze the theoretical aspects of methods for constructing optoelectronic systems, to identify contradictions arising at present in the improvement of such systems, and to determine ways of prospective development of theoretical models underlying the reception and processing of optical signals in optoelectronic systems.

Optoelectronic systems have found wide application in solving observation tasks under various lighting conditions. Currently, unique optoelectronic systems exist that provide observation of objects across a wide range of illumination levels.

However, at present there is a contradiction between the prospects for the development of television technology (modern capabilities of existing means) and the a priori information about the possibility of observing natural science objects. The potential capabilities of the systems include the need to expand the dynamic range of television systems, both towards registering strong signals and towards registering weak and ultra-weak signals, as well as ensuring signal reception against strong interference.

The problem of registering such objects comes down to detecting and calculating the parameters of small-sized and low-contrast objects, which is of great importance. Detection by television systems and determination of parameters of observed objects (at a signal-to-noise ratio less than 5) is currently not carried out, but is expedient and necessary in various fields.

Possible ways to expand the capabilities of optoelectronic systems include:

1. Lowering sensitivity thresholds in primary information processing devices by improving individual system units.
2. Matching the dynamic range of systems when registering optical signals through the use of spectral and neutral filters.
3. Improving information processing algorithms, taking into account the statistical characteristics of received signals in information processing systems.

Each of these directions is based on a rigorous physical-mathematical description of the model for receiving and processing optical signals.

The quality of a specific mathematical model and the limits of its applicability depend on how fully it accounts for factors characterizing observation conditions and their influence on the parameters of the described signals. When analyzing the applicability limits of various mathematical models, it is advisable to use different criteria for evaluating the effectiveness of optoelectronic systems. Such criteria include: signal-to-noise ratio, conditional probabilities of correct and false detection of objects, etc.

To describe optical signals under various observation conditions, different models must be used. The choice of fundamental physical principles and approaches forming the basis for mathematical models of signals should be made considering the characteristics of the described signals (e.g., intensity range) and the background, noise, and interference environment. Thus, when describing high-intensity signals, the principles of wave theory of light can be applied. When describing weak signals (e.g., signals from faint cosmic objects, signals under low illumination conditions), the corpuscular structure of optical radiation must be considered.

Analysis of existing development paths for optoelectronic systems has shown that both analog and digital signal processing methods are used, including spatial-coordinate and spatial-spectral methods. At each of these transformation stages-spectral redistribution of energy, linear and nonlinear filtering and differentiation – aimed at improving system parameters, the received stochastic signal may change its statistical characteristics. This, in turn, leads to changes in the accuracy of determining signal parameters and prevents achieving potential accuracy in delivering results with optimal probabilistic characteristics about observed objects and their parameters.

Consideration of these facts leads to the realization of an internal contradiction between existing methods of receiving and processing television information and the quality indicators of observed object characteristics.

However, the authors' decades-long applied research experience shows that the main technical characteristics of many existing optoelectronic systems can be significantly improved by applying modern physical-mathematical methods of optical signal reception and processing, based on stochastic-deterministic signal processing.

Research into modernization possibilities of various optoelectronic systems has shown that their characteristics can be significantly improved by optimizing signal processing algorithms based on more complete mathematical descriptions of signals and applying modern digital technologies in implementing these algorithms. For example, the sensitivity and image quality obtained with an observation device using an electron-optical converter can be increased 8-10 times, resolution improved 3–5 times, and viewing range extended 4-6 times.

The theoretical basis for modernization of optoelectronic systems, in our view, may be original mathematical models of optical signals, composed through the combined use of geometric optics, wave and corpuscular theory of light, as well as modern advances in statistical theory of information reception and processing, nonlinear signal filtering methods, statistical theory of random flows, and modern achievements in computing technology.

Considering the main approaches to signal description, it can be concluded that mathematical descriptions of signals in optoelectronic systems may be constructed using different representations of optical radiation structure and mechanisms of its interaction with optical tract elements. Thus, to evaluate the spatial position of signals in the photodetector plane, geometric optics principles may be used. The spatial distribution of the signal component from a cosmic object is described using wave representations of optical radiation structure and properties and diffraction theory of electromagnetic waves. To describe statistical characteristics of optical signals, elements of corpuscular (photon) theory of light and representations of optical radiation as a random photon flow must be used. To describe light interaction with absorbing matter and the process of photocarrier generation, elements of quantum-mechanical representations must be applied.

The basis for stochastic-deterministic description is the representation of optical radiation as a random flow describing light quanta performing Brownian motion under turbulent atmospheric conditions. When electromagnetic waves propagate in a medium with random large-scale inhomogeneities, due to multiple scattering effects, optical field fluctuations increase, and their characteristics can be described by statistical theory based on anomalous diffusion laws.

Description of propagation in randomly inhomogeneous media can be conducted by studying statistical properties of stochastic equations describing optical radiation propagation based on stable Lévy distributions. Non-Gaussian isotropic distributions possess asymmetric properties; the variance of the flow, and consequently all higher moments of stable distributions, are infinite – this is related to the behavior of probability density tails at large distances. Subordinated Lévy motion trajectories are characterized by jumps not only along coordinate axes but also along the time axis. The distribution of temporal characteristics of event occurrence in the flow has a power-law form rather than exponential, which provides grounds to consider it a non-Markovian process or a process with memory.

Interaction with the optical link of an optoelectronic system can be represented as the interaction of two independent stochastic flows. In this case, known methods of matching the dynamic range of input optical radiation and photosensitive elements of the optoelectronic system require separate study of changes in input radiation statistics.

Application of non-Gaussian isotropic distribution theory to describe optical signal reception and processing allows significantly reducing signal detection errors.

Accounting for sequentially changing statistics at all stages of radiation transformation creates a basis for synthesizing optimal algorithms for optical signal detection in optoelectronic systems.

In our opinion, the proposed approaches can be used in the creation of new optoelectronic devices, as well as for modernization of a number of existing optoelectronic systems applied in various fields, which will significantly improve their technical characteristics and enhance competitiveness.

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