Signal Detection Theory

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Signal detection theory is a well-known problem in signal processing. The issue of noise immunity in complex systems is the main problem in various areas of signal processing. At present there are many books and periodical articles devoted to signal detection theory, but many important problems remain to be solved; and work in signal detection theory for the purpose of increasing noise immunity is ongoing. New approaches to complex problems allow us not only to summarize investigations but also to improve the quality of signal detection in noise.

In modern practice, which is characterized by complex problems that are solved by signal processing systems, and a variety of interferences and noise, the design and construction of signal processing systems with high qualitative characteristics are possible only on the basis of modern optimization approaches of synthesis. The general problem of synthesis of complex signal processing systems may be separated into two particular categories: a choice of the best signals to attain the required results with due regard for the real situation, and optimal signal processing in noise. A priori uncertainty of the statistical characteristics of interferences and noise makes the design and construction of complex signal processing systems inherently difficult. This problem is caused by a necessity to yield a better quality for the receivers and transmitters with a view to ensuring high quality under changing interference and noise conditions. This problem may be solved in two ways: the first is to study the statistical characteristics of interference and noise; the second, to search for signal processing approaches offering the highest noise immunity.

The book is devoted to a new approach to a new generalized approach to signal detection theory. The main purpose is to present the basic fundamental concepts of the generalized approach to signal processing in noise and to show how it may be applied in various areas of signal processing. The generalized approach allows extension of the well-known boundaries of the potential noise immunity set up by classical and modern signal detection theories. New approaches for construction of detectors with the amplitude, frequency, and phase tracking systems based on the generalized approach are presented. This work summarizes the investigations carried out by the author over the last 20 years.

The book contains seven chapters. The first chapter deals with a brief description of the basic tenets of classical signal detection theory and analysis of the main avenues of investigation in modern signal detection theory. Classical and modern signal detection theories are critiqued from the viewpoint of determination of jointly sufficient statistics of the parameters of the likelihood functions. The need for additional information about the statistical parameters of the likelihood function is the main conclusion of the critique of classical and modern signal detection theories carried out by the author.

The second chapter deals with modification of the initial premises of classical and modern signal detection theories; theoretical design of the decision-making rules with the purpose of determining the jointly sufficient statistics of the mean and variance of the likelihood function; principles of construction of detectors based on the generalized approach to signal detection theory; and theoretical study of the generalized detectors, including determination of the distribution law and main statistical characteristics of the processes at the output of the generalized detector, definition of noise immunity for the generalized detector, and comparative analysis between the generalized detector and the optimal and asymptotic optimal detectors of classical and modern theories. All theoretical study is strengthened by computer modelling.

The third chapter focuses on construction of generalized detectors for the stochastic signals in various signal-processing systems. The likelihood functions and decision-making rules governing the use of generalized detectors for stochastic signals are designed. The distribution laws and main statistical characteristics of processes at the output of the generalized detector are adjusted. Also, comparative analysis between the generalized detectors for stochastic signals and the optimal and asymptotic optimal detectors of classical and modern theories is carried out. Finally, computer-modelling results are discussed.

The fourth chapter is devoted to the study of the possibility of using generalized detectors in signal processing systems in communications. Generalized detectors for stochastic signals are constructed for a number of cases. The influence of energy mismatching between the model signal and signal being studied on the detection performance of generalized detectors is examined. The effect of analog-to-digital conversion inference on the detection performance of the generalized detector is discussed. Also, comparative analysis of the detection performance by generalized detectors versus the optimal and asymptotic optimal detectors of classical and modern theories is carried out. Again, theoretical study is enhanced by computer modelling and experimental results.

The fifth chapter is concerned with a new method of estimation of the correlation functions of processes at the output of the generalized detectors. This method allows us to:

- determine the statistical characteristics in contrast with the existing methods more rigorously;
- determine the detection performance as a function of the signal base more rigorously.

Comparative analysis of the detection performance as function of the signal base between the generalized detectors and the optimal and asymptotic optimal detectors of classical and modern theories is carried out. Possible approaches to stabilization of the detection performance of generalized detectors excluding random parameters of the signal, are discussed. These detectors are constructed using the amplitude-frequency-phase tracking systems and allow us to:

- realize the potentially achieved detection performance of generalized detectors for signals with stochastic parameters;
- do away with the practical realization of detectors with quadrate channels, as is universally adopted in classical and modern signal detection theories.

The experimental detection performance of various complex signal-processing systems using generalized detectors with amplitude-frequency-phase tracking systems is discussed and compared with the analogous performance of modern signal processing systems. Theoretical study is supported by computer modelling and experimental results.

The sixth chapter is devoted to the experimental study of generalized detectors. Experimental investigations are carried out for powerful and weak signals. New features of signal detection using generalized detectors are discussed. Comparative analysis between generalized detectors and the optimal and asymptotic optimal detectors of classical and modern theories is carried out.

The decision function used for a definition of the threshold as applied to signal detection based on the generalized approach to signal detection theory is determined. Practical recommendations for employment of generalized detectors in various areas of signal processing such as radar, communications, navigation systems, wireless communications, mobile communications, sonar, acoustics, underwater signal processing, remote sensing, geophysical signal processing, and biomedical signal processing are discussed using a number of practical examples and applications.

The seventh chapter deals with the definition of the type of signals, which may be used to ensure high resolution and noise immunity of complex signal processing systems based on the generalized approach to signal detection theory. The general case of potential noise immunity for complex signal processing systems is defined more rigorously. The capacity of complex signal processing systems constructed on the basis of the generalized approach to signal detection theory is determined and compared with the capacity of the modern complex signal processing systems. Results of computer modelling and experiments are discussed.

The content of the book shows that is possible to raise the upper bound of the potential noise immunity for complex signal processing systems in various areas of signal processing in comparison with the noise immunity defined by classical and modern signal detection theories.
In my opinion the book is an excellent resource for understanding and solving problems in modern signal detection theories. Professionals, scientists, engineers, and researchers in electrical engineering, computer science, geophysics, and applied mathematics will benefit from using the techniques presented.

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