Topics in Non-Gaussian Signal Processing
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With 83 Illustrations
PREFACE

Non-Gaussian Signal Processing is a child of a technological push. It is evident that we are moving from an era of simple signal processing with relatively primitive electronic circuits to one in which digital processing systems, in a combined hardware-software configuration, are quite capable of implementing advanced mathematical and statistical procedures. Moreover, as these processing techniques become more sophisticated and powerful, the sharper resolution of the resulting system brings into question the classic distributional assumptions of Gaussianity for both noise and signal processes. This in turn opens the door to a fundamental reexamination of structure and inference methods for non-Gaussian stochastic processes together with the application of such processes as models in the context of filtering, estimation, detection and signal extraction. Based on the premise that such a fundamental reexamination was timely, in 1981 the Office of Naval Research initiated a research effort in Non-Gaussian Signal Processing under the Selected Research Opportunities Program.

The program, sponsored by the Mathematical Sciences Division of ONR, brought together many of the leading researchers in statistics and signal processing. In addition to a consistent three year funding profile, a number of workshops and program reviews were held (Austin, Texas, October 1981; Annapolis, Maryland, May 1982; Kingston, Rhode Island, November 1982; Mt. Hood, Oregon, June 1983; and Princeton, New Jersey, March 1984) which brought together program investigators and interested Navy personnel from various facilities to exchange views and share the latest results of their research. This kind of basic research activity, motivated by real Navy problems in the non-Gaussian area, has not been previously undertaken in this country in such a focused manner. This book represents the culmination of the Non-Gaussian Program by reviewing the progress made in the program as well as presenting new results, not published elsewhere.

The book consists of fifteen papers, divided into three sections: Modeling and Characterization; Filtering, Estimation and Regression; Detection and Signal Extraction.

The first section starts with three papers which study and characterize a variety of ocean acoustic noise processes. The paper by Brockett, Hinich and Wilson looks at Gaussianity from a time series point of view and computes the bispectrum. Interestingly, time series which pass univariate tests of normality are shown, by means of bispectrum computation, to be non-Gaussian and non-linear time series. Powell and Wilson utilize the Middleton Class A model to characterize the noise from biological sources and acoustic energy generated by seismic exploration. They also investigate a number of techniques to estimate the parameters in the Class A canonical representation. In the study by Machell, Penrod and Ellis, kernel density estimates are obtained for the instantaneous amplitude fluctuations using five ocean ambient noise environments. Tests of homogeneity, randomness and normality are used to test the validity of the stationary Gaussian assumption. The fourth paper, by Mohler and Kolodziej, develops a model for a class of non-linear, non-Gaussian processes - the conditional linear and bilinear processes. They go on to identify distributions in this class which arise in underwater acoustical signal processing problems such as optimal state estimation. The final paper in this section by Wegman and Shull discusses a data analytic tool for displaying graphically the structure of multivariate statistical data. The procedure is called the parallel coordinate representation. Illustrative applications are given to multichannel...
time series, correlations and clustering, and beamforming for short segments of ocean acoustical data.

The second section of papers deals with filtering and estimation problems in a non-Gaussian environment. In the first study, Rosenblatt explores the structure of linear, non-Gaussian processes. It is shown that one can learn more about the linear structure from the observations than in the Gaussian case, a fact which should be helpful in modeling non-Gaussian autoregressive and moving average schemes. Rao investigates a class of nonstationary processes, the class which is subject to a generalized Fourier analysis. For this harmonizable class, one can use generalized spectral methods to do sampling, linear filtering, and signal extraction. The formulas for these operations, i.e., least squares estimation of harmonizable processes, have the same functional form as the results for stationary processes. Martin and Yohai study a robust estimate of ARMA model parameters called the AM-estimate. This estimate is based on a robust filter-cleaner which replaces outliers with interpolates based on previously cleaned data. Asymptotic properties are established and conditions for consistency are discussed. The paper by Brunk applies a Bayes least squares procedure and orthogonal transformation and expansion to the estimation of regression functions. Conditions for joint asymptotic normality of the transformed variables are established and an example is given which transforms a spectral density estimation problem into a regression problem.

The third section deals with the detection and extraction of signals. In the first paper, Bell considers the class of spherically exchangeable processes and treats five explicit signal detection models in this context. Both parametric and nonparametric techniques are utilized. The author points out that his procedures are generalizations of tests commonly used, that these tests are reasonable, but that little precise information is available on their performance. Next, Dwyer treats in considerable detail the development of processing techniques for the non-Gaussian noise encountered in the Arctic ocean and from helicopters. Both noise fields show significant narrow-band components. He proposes a method for the effective removal of these components to enhance signal detectability. In the third paper of this section, Tufts, Kirsteins, et al consider signal detection in a noise environment assumed to contain signal-like interference and impulse noise as well as a weak stationary Gaussian component. They develop iterative processing techniques to identify, categorize, model, and remove the non-Gaussian noise components, leaving a weak stationary Gaussian noise in which the weak signal, if present, may be detected. In another publication [Reference 6], they apply their methodology to Arctic undersea acoustic data. In the fourth paper, Baker presents a number of results in signal detection and communications. These include the detection of non-Gaussian signals in Gaussian noise and signal detection in non-Gaussian noise modeled as a spherically-invariant process. Both of these detection problems are immediately applicable to sonar. Continuing with the assumption of spherically-invariant processes, he considers the problem of mismatched channels and the capacity associated with spherically-invariant channels. The fifth paper, by Schwartz and Thomas, treats detection in a non-Gaussian environment where narrowband non-Gaussian components may be present and/or where the noise field may be nonstationary. In particular, they consider a switched detector based partly on the Middleton Class A noise model. They also consider the detection of fading narrowband signals in non-Gaussian noise using a robust signal estimator in conjunction with a robust detector. The last paper, by Machell and Penrose, considers energy detection in the context of ocean acoustic noise fields. Real noise data from this environment is used to evaluate the performance of energy detectors and it is found that their effectiveness depends heavily on the tail weights of the underlying noise distributions.

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