②

PROGRESS REPORT FOR THE

OFFICE OF NAVAL RESEARCH

SUBMITTED TO

Dr. Rabinder N. Madan
Program Manager
Systems and Electromagnetic Theory
Office of Naval Research
800 N. Quincy St., Code 1114
Arlington, Virginia 22217-5000

Signal Processing in Impulsive Electromagnetic Interference

June 30, 1991

Principal Investigator

Serena M. Zabin
[redacted]
Assistant Professor
Georgia Institute of Technology
School of Electrical Engineering
Atlanta, Georgia 30332-0250
[redacted]

Title: Signal Processing in Impulsive Electromagnetic Interference

Principal Investigator: Serena M. Zabin

Location: Georgia Institute of Technology
School of Electrical Engineering
Atlanta, GA 30332

Telephone Number: (404) 853-9484

Grant Number: N00014-91-J-1334

R&T Number: 4148128---01

Scientific Officer: Dr. Rabinder N. Madan

SCIENTIFIC OBJECTIVE

Statistical signal processing functions such as signal detection, estimation, and identification play a key role in the development of effective communications, radar, and sonar systems. For example, advanced statistical methods are emerging as being particularly important in digital communications systems operating in channels corrupted by interference from such phenomena as multiple-access noise, intentional jamming, and impulsive noise sources. Conventional demodulation methods, such as coherent matched filtering, often suffer serious performance degradation when subjected to interference of these types; however, this degradation can frequently be eliminated through the use of more sophisticated signal processing techniques.

A central issue in the design of effective signal processing procedures for systems operating in channels such as those noted above is that of channel identification. Although certain aspects of channel identification have been studied extensively, one area in which there is a pressing need for further research is that of identification of impulsive channels. Communication systems are seldom interfered with by white Gaussian noise alone, yet receiving systems in general use are those which are optimum for white Gaussian noise. The man-made electromagnetic environment, and much of the natural one, is basically "impulsive," i.e., it has a highly structured form characterized by significant probabilities of large interference levels. In addition to the man-made electromagnetic environment, there are many other different, common and widely-used communications and remote-sensing type channels where impulsive noise dominates, e.g., extra-low-frequency (ELF) channels, urban radio networks, underwater acoustic channels, and telephone line channels. This is in contrast to the Gaussian noise processes inherent in transmitting and receiving elements. Since the conventional receivers are effectively linear, the impulsive character of the interference can drastically the performance of conventional systems. Furthermore, since it has been well-established that the performance of communications, radar, and sonar systems can be greatly enhanced if the true statistics of the channel are known and exploited, the problem of identification of impulsive noise channels is important in the development of systems that can approach the performance limits set by such channels.

This research project is concerned with the design and development of new nonlinear algorithms for identification of nongaussian noise processes and for reception of signals corrupted by nongaussian noise. In particular, the overall objectives of this research project are: (i) the development of suitable channel models for impulsive interference; (ii) the derivation and analysis of new globally optimum nonlinear estimation procedures for the identification of impulsive interference channels, and (iii) application of the developed algorithms in the design of optimum and sub-optimum adaptive receivers for the detection of signals in non-Gaussian noise environments.

RESEARCH SUMMARY

During this reporting period, the focus of our work has been on the problem of obtaining identification procedures for impulsive channels that are both asymptotically optimal and practically efficient. Only in this way can we guarantee that the channel identification procedures will accurately model the channel when intermediate-size samples of channel measurements are used, and that the performance of the identification procedures improves as the number of samples used increases. Our emphasis in this area has been on the development of algorithms for fitting the widely-accepted parametric Class A Middleton model to channel measurements. This model has two basic parameters that can be adjusted to fit a wide variety of impulsive noise phenomena occurring in practice.

Within the context of batch estimation, we have developed a consistent and asymptotically efficient estimator of the Class A parameters that is practically efficient as well [13]. The development of this estimator began with an improved method-of-moments estimator of the parameters based on the extraction of two moments chosen for their sensitivity to the channel parameters. We have shown that this moments estimator is relatively simple to implement and yields unique estimates of the parameters that converge to the true parameters at near-optimal rates. We have also shown, via an extensive simulation study, that the estimator yields good estimates of the parameters for moderate sample sizes but that a significant improvement in performance over the method-of-moments estimator is possible if an asymptotically efficient estimator can be found. By initiating Newton's root-finding method on the likelihood equation with the method-of-moments estimator, such an estimator was obtained. Moreover, via an extensive simulations study, it was seen that the proposed Moment/Likelihood procedure yields excellent estimates of the parameters for moderate sample sizes. In addition to the Moment/Likelihood procedure, we have developed an optimization scheme based on the simplex method that can be shown to converge to a relative maximum of the likelihood function. Preliminary analysis of this scheme indicates that it performs very well for small sample sizes. Current activity on the batch estimation problem includes the development of a nonparametric density estimator of the Class A density based on the kernel estimator, which is ideally suited for mixture densities such as the Class A density. This nonparametric identification procedure will be used in the design of robust receivers for detection of signals in Class A noise. Preliminary analysis of this scheme indicates that it also performs very well for small sample sizes.

During this period, we have also considered the problem of recursive estimation of the Class A parameters. Our primary focus has been on the development of recursive channel estimators that are efficient for small sample sizes. Only in this way can we guarantee that our channel estimator is capable of tracking rapidly-varying nongaussian channels. In particular, a global recursive estimator of the parameters is currently being developed that can overcome the shortcomings of conventional recursive stochastic gradient-type algorithms which make them unsuitable for impulsive channel identification. The primary shortcoming is that the conventional algorithms cannot uniquely identify the Class A parameters due to the existence of multiple roots in the asymptotic likelihood equation. This recursive estimator is based on the use of a nonstandard stochastic approximation procedure wherein the standard Fisher's information matrix, which governs the step size in the recursion, is replaced with a "complete-data" information matrix. This complete-data information matrix not only facilitates the implementation of the recursion but also yields a global procedure through which excellent estimates of the parameters are obtained for small sample sizes.

PUBLICATIONS

Journal Articles

[1] S. M. Zabin, H. V. Poor, "Parameter Estimation for Middleton Class A Interference Processes," *IEEE Transactions on Communications,* vol. COM-37, no. 10, pp. 1042-1051, 1989.

[2] S. M. Zabin, H. V. Poor, "Recursive Algorithms for Identification of Impulsive Noise Channels," *IEEE Transactions on Information Theory,* vol. 36, no. 3, pp. 559-578, 1990.

[3] S. M. Zabin, H. V. Poor, "Efficient Estimation of Class A Noise Parameters via the EM Algorithm," *IEEE Transactions on Information Theory,* vol. 37, no. 1, pp. 60-72, 1991.

[4] S. M. Zabin, "Optimal Identification of Impulsive Interference Processes," in preparation for submission to *IEEE Transactions on Information Theory.*

[5] S. M. Zabin, D. S. Furbeck, "Maximum Likelihood Estimation of Nongaussian Mixtures," in preparation for submission to *IEEE Transactions on Information Theory.*

Conference Papers

[6] S. M. Zabin, H. V. Poor, "Identification of Impulsive Electromagnetic Interference Channels," *Industrial Affiliates Program in Communications, Antennas, and Propagation, Eighth Annual Workshop,* University of Illinois at Urbana-Champaign, p. 18, April 1986.

[7] S. M. Zabin, H. V. Poor, "Parameter Estimation for the Class A Middleton Model," *Abstracts of Papers: 1986 IEEE International Symposium on Information Theory,* Ann Arbor, MI, p. 28, October 1986.

[8] S. M. Zabin, H. V. Poor, "Recursive Estimation of the Class A Noise Model Parameters," *Proceedings of the 22nd Annual Conference on Information Sciences and Systems,* Princeton University, Princeton, NJ, p. 178, March 1988.

[9] S. M. Zabin, H. V. Poor, "New Algorithms for the Identification of Impulsive Noise," *Abstracts of Papers: 1988 IEEE International Symposium on Information Theory,* Kobe, Japan, p. 31, June 1988.

[10] S. M. Zabin, H. V. Poor, "Estimation of Impulsive-Channel Parameters via the EM Algorithm," *Proceedings of the 1989 Conference on Information Sciences and Systems,* The Johns Hopkins University, Baltimore, MD, p. 301, March 1989.

[11] S. M. Zabin, H. V. Poor, "Optimum Identification of Impulsive Interference Channels," *Industrial Affiliates Program in Communications, Electromagnetics, Propagation, and Signal Processing, Eleventh Annual Workshop,* University of Illinois at Urbana-Champaign, p. 27, April 1989.

[12] S. M. Zabin, H. V. Poor, "Efficient Identification of Impulsive Channels," *Abstracts of Papers: 1990 IEEE International Symposium on Information Theory,* San Diego, California, p. 96, January 1990.

[13] S. M. Zabin, "Optimum Identification of Impulsive Noise Processes," to be presented at the *1991 IEEE International Symposium on Information Theory,* June 1991.

Technical Reports and Theses

[14] S. M. Zabin, "Parameter Estimation for the Class A Middleton Model," M.S. Thesis, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign. Also Tech. Rep. No. R-1048, UILU-ENG85-2223, July 1985.

[15] S. M. Zabin, "Identification of Impulsive Interference Channels," Ph.D. Dissertation, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, July 1989. Also Tech. Rep. UILU-ENG-89-2224, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign.