AD-A260 833

SEMIANNUAL TECHNICAL REPORT FOR RESEARCH GRANT FOR 1 JUL. 92 TO 31 DEC. 92

Grant No: N0001492-J-1218

Grant Title: Exploitation of Cyclostationarity for Signal-Parameter Estimation and System Identification

Principal Investigator: William A. Gardner
(Co-PI Stephan V. Schell)

Mailing Address: Department of Electrical and Computer Engineering
University of California
Davis, CA 95616-5294

Phone Number: 916-752-1951 (or -0583)

FAX: 916-752-8428

PROJECT SUMMARY

The cyclostationarity property of communications and telemetry signals enables the generation of spectral lines with appropriate nonlinear transformations and renders fluctuations in distinct spectral bands statistically dependent. The frequencies at which spectral lines can be generated are directly related to the separations between dependent spectral bands, which in turn are directly related to carrier frequencies, keying rates, pulse rates, and so on, in the signal. These inherent properties of cyclostationary signals can be exploited to great advantage for numerous tasks in signal processing. The objectives of the research being conducted are to investigate new cyclostationarity-exploiting methods for (1) signal-selective high-resolution direction finding using sensor arrays, (2) selectively locating emitters by time difference and frequency difference measurement with one or more pairs of sensors, (3) identifying the kernels in the Volterra series representation of nonlinear time-invariant and multiply-periodic systems.

TITLES OF RESEARCH PAPERS SUBMITTED FOR PUBLICATION

1. W. A. Gardner, "An Introduction to Cyclostationary Signals," in Proceedings of the Workshop on Cyclostationary Signals, SSPI Publishing, August 1992.

2. S. V. Schell and W. A. Gardner, "Robustness of Direction-Finding Methods for Cyclostationary Signals in the Presence of Array Calibration Error," Proceedings of the IEEE Sixth Signal Processing Workshop on Statistical Signal and Array Processing, October 1992.

3. S. V. Schell, "Generalization of Whittle's Theorem to Cyclostationary Signals," Proceedings of the IEEE Sixth Signal Processing Workshop on Statistical Signal and Array Processing, October 1992.

4. S. V. Schell, "Asymptotic Moments of Estimated Cyclic Correlation Matrices," IEEE Transactions on Signal Processing.

5. S. V. Schell, "Performance Analysis of the Cyclic MUSIC Method of Direction Estimation for Cyclostationary Signals," IEEE Transactions on Signal Processing.

ABSTRACTS OF SUBMITTED RESEARCH PAPERS

1. AN INTRODUCTION TO CYCLOSTATIONARY SIGNALS:

Many conventional statistical signal processing methods treat random signals as if they were statistically stationary, in which case the parameters of the underlying physical mechanism that generates the signal would not vary with time. But for most manmade signals encountered in communication, telemetry, radar, and sonar systems, some parameters do vary periodically with time. In some cases even multiple incommensurate (not harmonically related) periodicities are involved. Examples include sinusoidal carriers in amplitude, phase, and frequency modulation systems, periodic keying of the amplitude, phase, or frequency in digital modulation systems, and periodic scanning in television, facsimile, and some radar systems. Although in some cases these periodicities can be ignored by signal processors, such as receivers which must detect the presence of signals of interest, estimate their parameters, and/or extract their messages, in many cases there can be much to gain in terms of improvements in performance of these signal processors by recognizing and exploiting underlying periodicity. This typically requires that the random signal be modeled as *cyclostationary*, in which case the statistical parameters vary in time with single or multiple periodicities. Cyclostationarity also arises in signals of natural origins, due to the presence of rhythmic, seasonal, or other cyclic behavior. Examples include time-series data encountered in meteorology, climatology, atmospheric science, oceanology, astronomy, hydrology, biomedicine, and economics. This article introduces the field of study encompassing the theory of cyclostationary signals and the exploitation of the cyclostationarity property.

2. ROBUSTNESS OF DIRECTION-FINDING METHODS FOR CYCLOSTATIONARY SIGNALS IN THE PRESENCE OF ARRAY CALIBRATION ERROR:

In this paper it is shown that cyclostationarity-exploiting direction-finding methods can be much less sensitive than conventional direction-finding methods to errors in the array calibration data. In particular, when only a small subset of the signals arriving at the array exhibits the desired cyclostationarity property, it is shown that the signal-selective methods can operate properly in the presence of calibration errors that cause the conventional methods to fail.

3. GENERALIZATION OF WHITTLE'S THEOREM TO CYCLOSTATIONARY SIGNALS:

Whittle's Theorem greatly facilitates the computation of the Cramér-Rao Bound (CRB) for stationary signals by establishing that the Fisher Information matrix can be asymptotically re-expressed in terms of the spectral density matrix, which for stationary signals is diagonal and thus is easily invertible. However, since almost all man-made communication signals exhibit cyclostationarity rather than stationarity, Whittle's Theorem rarely applies to such signals. Furthermore, recently developed estimation methods that exploit cyclostationarity can exhibit error covariance well below the CRB for parameters of corresponding stationary signals. The CRB for parameters of cyclostationary signals is required to properly bound the performance of these new methods, and its computation would be greatly simplified by an appropriate generalization of Whittle's Theorem. In this paper a generalization of Whittle's Theorem that accommodates cyclostationary signals is proposed and examples of its application to computing the CRB for parameters of cyclostationary signals are given.

4. ASYMPTOTIC MOMENTS OF ESTIMATED CYCLIC CORRELATION MATRICES:

The first and second moments of the cyclic cross-correlogram matrix of two vector-valued Gaussian cyclostationary processes are derived in this paper. These results generalize those of Hurd to accommodate multiple incommensurate cycle frequencies and complex vector-valued discrete-time processes. As an example application of the results, the first and second moments of the left singular vectors of the cyclic cross-correlogram matrix are derived, which are needed in the performance analysis of subspace-fitting methods of direction-of-arrival estimation for cyclostationary signals.

5. PERFORMANCE ANALYSIS OF THE CYCLIC MUSIC METHOD OF DIRECTION ESTIMATION FOR CYCLOSTATIONARY SIGNALS:

The bias and mean-squared error of the direction estimates obtained by Cyclic MUSIC are derived in this paper under the assumption that complex Gaussian cyclostationary signals arrive at the array of sensors. The analytical results are shown to be excellent predictors of empirical results obtained from computer simulation of the Cyclic MUSIC algorithm, and are also compared with the Cramér-Rao Bound, which in certain cases can be orders of magnitude less than the Cramér-Rao Bound for the directions-of-arrival of stationary signals.