Hindawi Publishing Corporation
EURASIP Journal on Advances in Signal Processing
Volume 2011, Article ID 963642, 3 pages
doi:10.1155/2011/963642

Editorial

Recent Advances in Theory and Methods for Nonstationary Signal Analysis

Patrick Flandrin (EURASIP Member),[1] Antonio Napolitano (EURASIP Member),[2] Haldun M. Ozaktas,[3] and David J. Thomson[4]

[1] *Département de Physique (UMR CNRS 5672), École Normale Supérieure de Lyon, 69364 Lyon Cedex 07, France*
[2] *Department of Technology, University of Napoli "Parthenope", 80143 Napoli, Italy*
[3] *Department of Electrical Engineering, Bilkent University, 06800 Bilkent, Ankara, Turkey*
[4] *Department of Mathematics and Statistics, Queen's University, Kingston, ON, Canada K7L 3N6*

Correspondence should be addressed to Antonio Napolitano, antonio.napolitano@uniparthenope.it

Received 3 March 2011; Accepted 3 March 2011

All physical processes are nonstationary. When analyzing time series, it should be remembered that nature can be amazingly complex and that many of the theoretical constructs used in stochastic process theory, for example, linearity, ergodicity, normality, and particularly stationarity, are mathematical fairy tales. There are no stationary time series in the strict mathematical sense; at the very least, everything has a beginning and an end. Thus, while it is necessary to know the theory of stationary processes, one should not adhere to it dogmatically when analyzing data from physical sources, particularly when the observations span an extended period. Nonstationary signals are appropriate models for signals arising in several fields of applications including communications, speech and audio, mechanics, geophysics, climatology, solar and space physics, optics, and biomedical engineering. Nonstationary models account for possible time variations of statistical functions and/or spectral characteristics of signals. Thus, they provide analysis tools more general than the classical Fourier transform for finite-energy signals or the power spectrum for finite-power stationary signals. Nonstationarity, being a "nonproperty" has been analyzed from several different points of view. Several approaches that generalize the traditional concepts of Fourier analysis have been considered, including time-frequency, time-scale, and wavelet analysis, and fractional Fourier and linear canonical transforms. Approaches that generalize the power-spectrum analysis include cyclostationary signal analysis, multitaper spectral estimation, and evolutionary spectral analysis. In addition, techniques such as adaptive system and signal analysis, empirical mode decomposition, and other data-driven methods have been used with the purpose of modeling nonstationary phenomena.

In this special issue, recent advances in the theory and methodologies for nonstationary signal analysis are addressed, different approaches are compared, emerging or new techniques are proposed, and new application fields are explored. Of the 51 papers submitted, only 19 were accepted after the review process.

Four papers are related to basic topics of nonstationary signal analysis such as *instantaneous frequency estimation*, *time-frequency detection*, *Zak transform*, *and AM-FM analysis*.

In the paper "*An efficient algorithm for instantaneous frequency estimation of nonstationary multicomponent signals in low SNR*" by J. Lerga et al., a method for components instantaneous frequency (IF) estimation of multicomponent signals in low signal-to-noise ratio (SNR) is proposed. The method combines a new modification of a blind source separation algorithm for components separation, with the improved adaptive IF estimation procedure based on the modified sliding pairwise intersection of confidence intervals rule.

In the paper "*Time-frequency detection of slowly varying periodic signals with harmonics: methods and performance evaluation*" by J. O'Toole and B. Boashash, two methods to detect slowly varying periodic signals with harmonic components are presented. Both methods are based on different modifications of the time-frequency-matched filter and attempt to overcome the problem of predefining the template set for the matched filter. The ambiguity filter method reduces the number of required templates by one half; the time-frequency correlator method does not require a predefined template set at all.

In the paper "*Construction of sparse representations of perfect polyphase sequences in Zak space with applications to radar and communication*" by A. K. Brodzik, it is shown that the Zak space analysis of a chirp produces a highly compactified chirp, with support restricted to an algebraic line. In contrast, discrete Fourier transform of a chirp is, essentially, a chirp, with support similar to the support of the time-domain signal. Further investigation leads to relaxation of the original restriction to chirps, permitting construction of a wide range of polyphase sequence families with ideal correlation properties. The paper also contains an elementary introduction to the Zak transform methods, a survey of recent results in Zak space sequence design and analysis, and a discussion of the main open problems in this area.

In the paper "*Tree image growth analysis using instantaneous phase modulation*" by J. Ramachandran et al., the use of Amplitude-Modulation Frequency-Modulation (AM-FM) methods for tree growth analysis is proposed. For this application the authors introduce the use of fast filter bank filter coefficient computation based on piecewise linear polynomials and radial frequency magnitude estimation using integer-based Savitzky-Golay filters for derivative estimation.

Two papers address the problem of *spectrum and covariance function estimation* for nonstationary processes. In both papers the class of the locally stationary processes is considered in detail.

In the paper "*Optimal multitaper Wigner spectrum estimation of a class of locally stationary processes using Hermite functions*" M. Hansson-Sandsten investigates discrete-time multitapers that give an optimal Wigner spectrum estimate for a class of locally stationary processes. It is shown that the optimal multitapers are well approximated by Hermite functions (which is computationally efficient) and that a limited number of windows can be used for a mean square error optimal spectrogram estimate. Comparisons with other frequently used methods are provided.

In the paper "*Optimal nonparametric covariance function estimation for any family of nonstationary random processes*" by J. Sandberg and M. Hansson-Sandsten, the covariance function estimate of a zero-mean nonstationary random process in discrete time is accomplished from one observed realization by weighting observations with a kernel function. Several kernel functions have been proposed in the literature. The authors prove that the mean square error (MSE) optimal kernel function for any parameterized family of random processes can be computed as the solution to a system of linear equations. Even though the resulting kernel is optimized for members of the chosen family, it seems to be robust in the sense that it is often close to optimal for many other random processes as well.

Three papers are concerned with applications of *wavelet and wideband signal processing*.

In the paper "*Nonstationary system analysis methods for underwater communications*" by N. Josso et al., following a linear time-varying wideband system representation, two methods for estimating the underwater communication environment are proposed. The first one is based on estimating discrete wideband spreading function (WSF) coefficients from a canonical time-scale system representation. The second one follows a ray system model and estimates a highly localized WSF using the matching pursuit decomposition algorithm by extracting time-scale features for different ray paths.

In the paper "*Synthesis of an optimal wavelet based on auditory perception criterion*" by A. Karmakar et al., a method is proposed for synthesizing an optimal wavelet based on auditory perception criterion for dyadic filter bank implementation. The design method of this perceptually optimized wavelet is based on the critical band structure and the temporal resolution of human auditory system. The construction of this compactly supported wavelet is done by designing the corresponding optimal finite impulse response quadrature mirror filter (QMF).

In the paper "*A signal-specific QMF bank design technique using Karhunen-Loève transform approximation*" by M. Dogan and O. N. Gerek, a signal-specific method of QMF bank design is proposed. The method uses the Karhunen-Loève transform (KLT) matrix which is specific for the statistical characteristics of the signal and compresses the signal with the maximum coding gain. A block wavelet transform (BWT) inversion method is proposed which designs the QMF banks by matching the BWT matrix to the KLT matrix.

Since its introduction some ten years ago, the technique of "*Empirical Mode Decomposition*" *(EMD)* has gained an increased popularity in the analysis of nonstationary signals. Two papers of this special issue are concerned with EMD.

In the first one, "*Multivariate empirical mode decomposition for quantifying multivariate phase synchronization*" A. Y. Mutlu and S. Aviyente make use of a recent extension of EMD to multivariate data for getting a robust description of time-varying phase synchrony between channels. They evidence that their approach can be used for quantifying multivariate synchronization within a network of oscillators, with an application to electroencephalogram (EEG) data.

In the second paper, "*Evaluation of empirical mode decomposition for event-related potential analysis*" N. Williams et al. investigate the potentiality of EMD for denoising those EEG signals that correspond to weak modifications due to a stimulus. They show in particular the gain offered by the new technique, as compared to more classical filtering operations assuming a form of stationarity.

One paper exploits *cyclostationary signal analysis* for mechanical applications.

In the paper "*Electrical noise cancelation for bearings damage detection using stator current and voltage*" by A. Ibrahim et al., the problem of detection of a bearing defect in an asynchronous machine is addressed. For this purpose, it is considered that the voltage is imposed and is independent of mechanical aspects and that the mechanical defect appears only in the current signal via the impedance variation. Cyclostationary signal analysis and Wiener filtering are used to extract mechanical information contained into the electrical current signal. Then statistical indicators such as kurtosis are adopted to highlight the presence of a defect.

Theoretical results and applications are presented in several fields such as DNA sequence analysis, biomedical signal analysis, system identification, mechanical systems, communications.

In the paper "*Short exon detection in DNA sequences based on multifeature spectral analysis*" by N. Y. Song and H. Yan, DNA bending stiffness, disrupt energy, free energy, and propeller twist properties are analyzed by an autoregressive (AR) model. The linear prediction matrices for the four features are combined to find the same set of linear prediction coefficients, from which the spectrum of the DNA sequence is estimated and exons are detected based on the 1/3 frequency component. Moving windows of different sizes in the AR model are used to account for the non-stationarity of DNA sequences.

In the paper "*Selection of nonstationary dynamic features for obstructive sleep apnea detection in children*" by L. M. Cano et al., a methodology for selecting a set of relevant nonstationary features to increase the specificity of the obstructive sleep apnea detector is proposed. Specifically, dynamic features are extracted from time-evolving spectral representation of photoplethysmography envelope recordings.

In the paper "*A self-adaptive approach for the detection and correction of stripes in the sinogram: suppression of ring artifacts in CT imaging*" by A. N. M. A. N. M. Ashrafuzzaman et al., novel techniques are proposed for the detection and suppression of ring artifacts in computed tomography (CT) imaging. First-and second-order derivatives of the sinogram are exploited. In addition, a new method for the detection of wideband contiguous stripes using the mean curve and multilevel polyphase decomposition of the given sinogram is also proposed.

In the paper "*Mean-square performance analysis of the family of selective partial update NLMS and affine projection adaptive filter algorithms in nonstationary environment*" by M. S. E. Abadi and F. Moradiani, a general framework is presented for mean-square performance analysis in nonstationary environment of the selective partial update affine projection algorithm (SPU-APA) and the family of SPU normalized least mean-squares (SPU-NLMSs) adaptive filter algorithms.

In "*An improved flowchart for Gabor order tracking with Gaussian window as the analysis window*" by Y. Jin and Z.-Y. Hao, an improved flowchart for Gabor order tracking is proposed, which eliminates the try-and-error process of analysis parameters.

In the paper "*Performance of post-demodulator adaptive filters for FSK signals in a multipath environment*" S.-T. Lee et al. extend understanding of the post-demodulator filter and demonstrate that the statistical assumptions that align bit error rate (BER) performance with MSE performance do not apply in this context and that simply decreasing the MSE might increase the BER rather than decrease it. An alternative post demodulator adaptive filter with similar complexity to the least mean square (LMS) filter is proposed which shows improved BER performance.

In the paper "*A study on conjugate quadrature filters*" by J.-S. Leng and T.-Z. Huang, a general method to construct a $(J + 1)$-length conjugate quadrature filter (CQF) with multiplicity r and scale a starting from a J-length CQF is obtained. As a special case, the authors address the construction of a $(J + 1)$-length CQF with multiplicity 2 and scale 2 which can generate a compactly supported symmetric-antisymmetric orthonormal multiwavelet system starting from a J-length CQF.

Acknowledgment

H. M. Ozaktas acknowledges partial support of the Turkish Academy of Sciences.

Patrick Flandrin
Antonio Napolitano
Haldun M. Ozaktas
David J. Thomson