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Editorial

Robust Processing of Nonstationary Signals

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Techniques for processing signals corrupted by non-Gaussian noise are referred to as the robust techniques. They have been established and used in science in the past 40 years. The principles of robust statistics have found fruitful applications in numerous signal-processing disciplines especially in digital image processing and signal processing for communications. Median, myriad, meridian, L filters (with their modifications), and signal-adaptive realizations form a powerful toolbox for diverse applications. All of these filters have low-pass characteristic. This characteristic limits their application in analysis of diverse nonstationary signals where impulse, heavy-tailed, or other forms of the non-Gaussian noise can appear: FM, radar and speech signal processing, and so forth. Recent research activities and studies have shown that combination of nonstationary signals and non-Gaussian noise can be observed in some novel emerging applications such as internet traffic monitoring and digital video coding.

Several techniques have been recently proposed for handling signal filtering, parametric/nonparametric estimation, and feature extraction, of nonstationary and signals with high-frequency content corrupted by non-Gaussian noise. One approach is based on filtering in time domain. Here, the standard median/myriad forms are modified in such a manner to allow negative and complex-valued weights. This group of techniques is able to produce all filtering characteristics: high-pass, stop-band, and band-pass. As an alternative, the robust filtering techniques are proposed in spectral (frequency-Fourier, DCT, wavelet, or in the time-frequency) domain. The idea is to determine robust transforms having ability to eliminate or surpass influence of non-Gaussian noise. Then, filtering, parameter estimation, and/or feature extraction is performed using the standard means. Other alternatives are based on the standard approaches (optimization, iterative, and ML strategies) modified for nonstationary signals or signals with high-frequency content.

Since these techniques are increasingly popular, the goal of this special issue is to review and compare them, propose new techniques, study novel application fields, and to consider their implementations.

In this special issue, we have been able to select 11 papers on a variety of related topics.

The first three papers are related to processing of FM signals in the spectral and the time-frequency domains. The main tool is the robust DFT that can be used for development of various robust tools in the spectral domain.

The paper "*An overview of the adaptive robust DFT*" (A. Roenko et al.) presents an overview of the basic principles and applications of the robust-DFT approach, which is used for robust processing of frequency-modulated signals embedded in non-Gaussian heavy-tailed noise. In particular, it has concentrated on the spectral analysis and filtering of signals corrupted by impulsive distortions using adaptive and nonadaptive robust estimators. Several adaptive estimators of location parameter are considered, and it is shown that their application is preferable with respect to nonadaptive counterparts. This fact is demonstrated by efficiency comparison of adaptive and nonadaptive robust DFT methods for different noise environments.

The paper entitled "*Robust time-frequency distributions with complex-lag argument*" (N. Žarić et al.) considers obtaining highly concentrated time-frequency representations for signals corrupted with impulsive/heavy-tailed noise. The proposed approach combines the robust DFT evaluation in order to get filtered signal with removed and/or reduced influence of the impulsive noise and the time-frequency representations with the complex time argument for producing highly concentrated representations. The proposed approach has been tested for the instantaneous frequency estimation showing high accuracy and stability. In addition, the approach is modified for multicomponent signals case.

The third paper in this section "*Two-Dimensional harmonic retrieval in correlative noise based on genetic algorithm*" (S. Wu et al.) considers the two-dimensional (2-D) harmonic retrieval in the presence of correlative zero-mean and multiplicative and additive noise. First, a 2-D fourth-order time-average moment spectrum which has maximal values at the harmonic frequencies is introduced. Then, the problem of harmonic retrieval is treated as a problem of finding the maximal values in the GA. Utilizing the global searching ability of the GA, this method can improve the frequency estimation performance. The effectiveness of the proposed algorithm is demonstrated through computer simulations.

The second section is related to the image filtering and restoration with three papers proposing novel techniques in this quite competitive field.

Filtering of impulse noise for digital images has been considered in paper "*Impulse noise filtering using robust pixel-wise S-estimate of variance*" (V. Crnojević et al.). The S-estimate is used as an alternative technique for estimating variance to commonly accepted tools such as the MAD estimator. Namely, the S-estimate has shown excellent accuracy for nonsymmetric skewed noise distributions. It is important to note that such distributions are frequently encountered in the transition regions of images. The derived S-estimator of variance is used for efficient iterative technique for impulse noise filtering. The stopping criteria of the algorithm are also developed using the S-estimator. Efficiency and accuracy of the proposed filter have been demonstrated on numerical examples and tested against the state-of-the-art in the field.

A new variational image model for image restoration using a combination of the curvelet shrinkage method and the total variation (TV) functional is presented in "*Image variational denoising using gradient fidelity on curvelet shrinkage*" (L. Xiao et al.). The staircasing effect and curvelet-like artifacts are suppressed using the multiscale curvelet shrinkage. A new gradient fidelity term is designed to force the gradients of desired image to be close to the curvelet approximation gradients. To improve the ability to preserve the details of edges and texture, the spatial-varying parameters are adaptively estimated in the iterative process of the gradient descent flow algorithm. Numerical experiments demonstrate that the proposed method has good performance in alleviating both the staircase effect and curvelet-like artifacts, while preserving fine details.

The generalized Cauchy distribution (GCD) is developed in "*A generalized Cauchy distribution framework for problems requiring robust behavior*" (R. E. Carillo et al.). Accurate pdf estimation and modeling is important for development of sample processing theories and methods. The GCD family has a closed-form pdf expression across the whole family as well as algebraic tails, which makes it suitable for modeling many real-life impulsive processes. This paper develops a GCD theory-based approach that allows challenging problems to be formulated in a robust fashion. Notably, the proposed framework subsumes generalized Gaussian distribution (GGD) family-based developments, thereby guaranteeing performance improvements over traditional GCD-based problem formulation techniques. This robust framework can be adapted to a variety of applications in signal processing. As examples, four practical applications under this framework are presented: (1) filtering for power line communications, (2) estimation in sensor networks with noisy channels, (3) reconstruction methods for compressed sensing, and (4) fuzzy clustering.

The section on its own is the paper "*Two-Stage outlier elimination for robust curve and surface fitting*" (J. Yu et al.). The authors proposed approach for outlier elimination based on the two-stage procedure with proximity-based outlier detection followed by model-based one. Depending on the hard/soft threshold of the connectivity of observations, two algorithms are developed for the proximity-based outlier detection: graph-component-based and eigenspace-based. The second stage iteratively refits and retests the information about shape or contour until convergence. These two stages are convenient for removing various types of outliers that can appear. Comparing existing approaches, the proposed technique produces significantly improved results for ellipse/ellipsoid fitting for large portion of outliers and high level of noise.

The section related to applications is particularly strong.

The paper "*Channel characterization and robust tracking for diversity reception over time-variant off-body wireless communication channels*" (P. Van Torre et al.) considers application of the robust processing tools in communication systems. It seems that the novel and future communication schemes will be important user and motivation field for tools developed in the robust processing of nonstationary signals. In the paper, 2.45 GHz band, indoor wireless off-body data communication with moving person is considered. This communication can be problematic due to time-variant signal fading and the consequent variation in channel parameters. Off-body communication specifically suffers from the combined effects of fading, shadowing, and path loss due to time-variant multipath propagation in combination with shadowing by the human body. Measurements are performed to analyze the autocorrelation, coherence time, and power spectral density for a person equipped with a wearable receiver system moving at different speeds for different configurations and antenna positions. Diversity reception with multiple textile antennas integrated in the clothing provides improved link reliability. For the dynamic channel estimation, a scheme using hard decision feedback after MRC with adaptive low-pass filtering is demonstrated to be successful in providing robust data detection for long data bursts, in the presence of dramatic channel variation.

The paper "*Data fusion for improved respiration rate estimation*" (S. Nemati et al.) considers very difficult problems of estimation of respiratory rates from passively breathing subjects. The main novelty in the paper is the estimation using various sources. Namely, in practice, the best source is commonly selected according to the available criterion while other recordings are discarded. In the proposed approach, the various data sources are fused using an instance of the Kalman filter based on developed signal quality index. The proposed technique is not only tested on both real recordings, but also on the case of the artificially added noise. The proposed technique has shown reasonable robustness to the noise influence. The real data set used in the study is obtained from 30 subjects and contains the ECG and respiration and peripheral tonometry.

The paper "*Improved noise minimum statistics estimation algorithm for using in a speech passing noise rejection headset*" (S. Sayedtabaee et al.) deals with the practical industrial noise produced by rotating machinery (in this case, angle grinder). The problem is the fact that the strong angle grinder noise should be removed but oral communication should be preserved as much as possible. The headset for removing such noise is constructed with the installed microphone and speaker. The spectral substraction method is modified in order to achieve the angle grinder noise removal. Noise is estimated employing a multiband adaptive scheme. The algorithm adopts to changes of the noise characteristics in very fast manner with minimal distortion of other useful signals. The accuracy of the algorithm is tested using objective and subjective measures.

The paper "*Adaptive wavelet transform method to identify cracks in gears*" (A. Belsak et al.) describes de-noising method based on wavelet analysis which takes prior information about impulse probability density into consideration. This method is used to identify transient information from vibration signals of a gear unit with a fatigue crack in the tooth root. This important practical problem due to a crack in the tooth root is one of the most dangerous problems that can cause failure in gear unit operation. The proposed robust technique employs filtering since recorded signals are quite noisy, making determination of properties of individual components a very difficult task.

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