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Estimation of Noise Variance Using the Weighted EMD Coefficients of the Noisy Signal

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Abstract

This paper proposes a noise variance estimation method using the Empirical Mode Decomposition (EMD) of signals and the characteristics of the decomposed layers. The main idea is based on the fact that the layers obtained from the EMD decomposition of the noisy signal will contain several layers with some pure signal components, several layers in the form of pure noise, and layers in the form of a combination of signal and noise. According to the definition of signal and noise in this study, the highest signal power is in the final layers, and the highest noise power is in the initial layers of the decomposition. Based on this principle, the noise variance was estimated by calculating the noise energy and the correlation of the noise with different sub-signals from each layer. Based on the simulation results, it is observed that the proposed method in estimating the noise variance has an error reduction of about 1.5, 3.5 and 1.7 percent, respectively, compared to the Maciej, Elvander, Cai and Wang methods.

Keywords:

Correlation of noise, Empirical mode decomposition method, Noise variance estimation.

1. Introduction

Noise identification and reduction is a well-known problem in many applications, especially in signal processing, and we know that one of the important characteristics of noise is its variance; therefore, noise variance estimation has a fundamental role in various aspects of signal processing. In [1], the authors employed Empirical Mode Decomposition method to decompose the noisy signal, estimated its variance based on the noise energy, and subsequently proceeded to reduce the noise using the Variable Mode Decomposition method. This paper investigates noise variance estimation by decomposing the signal using the Empirical Mode Decomposition (EMD) method and utilizing the characteristics of the resulting decomposed layers. A significant advantage of this decomposition method over alternatives (such as filtering, Independent/Dependent Component Analysis, neural networks, and adaptive filters) is its applicability to any type of signal. Since the method performs decomposition based solely on the signal's intrinsic properties and does not require knowledge of the pure (noise-free) signal for its calculations, it offers high reliability.

2. Methodology

The flowchart of the proposed method is shown in Figure (1):

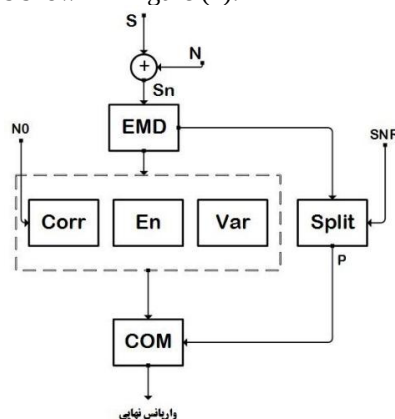


Figure 1. The flowchart of the proposed method

First, the noisy signal is decomposed into its Intrinsic Mode Functions (IMFs) using the EMD method [2]:

$$S_N(n) = \sum_{i=1}^{L-1} IMF_{iS_N(n)} + r(n) \quad (1)$$

Subsequently, for each of these components, the variance (Var), energy (En), and correlation (Corr) with the initially estimated noise (N_0) are calculated. Additionally, the P components that exert the greatest effect on the noise variance are selected and combined to estimate the final noise variance. Noise energy has a direct effect on noise variance and, consequently, a direct effect on the linear combination coefficient λ_i :

$$\lambda_i = \frac{0.64 \times e_{n_i}}{2^{2(i-1)} \times \sigma_{IMF_{iS_N(n)}}^2} \quad (2)$$

Finally, the relation $\sigma_{N(n)}^2$, based on normalization, is expressed as:

$$\sigma_{N(n)}^2 = \frac{\sum_{i=1}^P \lambda_i \times (\sigma_{iN(n)}^2)}{\sum_{i=1}^P \lambda_i} = \frac{\sum_{i=1}^P \frac{0.64 \times e_{n_i} \times (\sigma_{iN(n)}^2)}{2^{2(i-1)} \times \sigma_{IMF_{iS_N(n)}}^2}}{\sum_{i=1}^P \frac{0.64 \times e_{n_i}}{2^{2(i-1)} \times \sigma_{IMF_{iS_N(n)}}^2}} \quad (3)$$

where, $\sigma_{iN(n)}^2$ represents the estimated noise variance for the i -th layer. This research found that the accuracy of noise variance estimation is improved through a linear combination of the variances from the various layers.

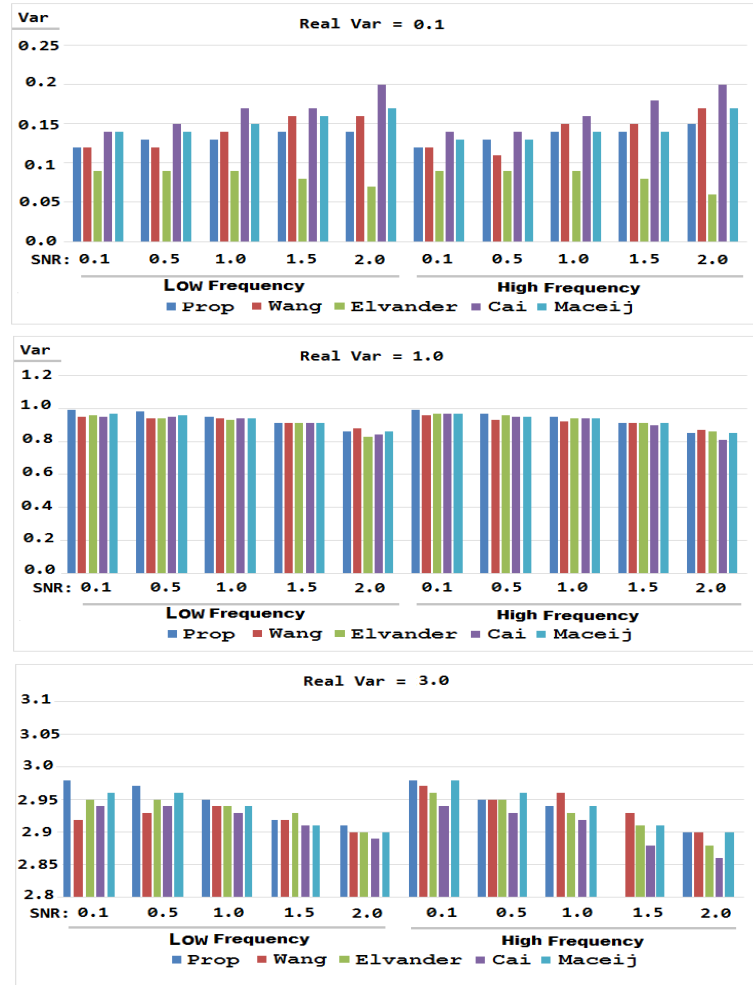


Figure 2. Comparison of the estimated variance of the proposed method with existing methods

3. Results and Discussion

This section presents the results obtained from the proposed method and compares them with existing methods [3-4]. For the simulation, a signal $S(n)$ was used, consisting of a combination of chirp, sinusoidal, exponential, and pulse signals, along with noise characterized by an SNR in the range $0 \leq |\text{SNR}| < 2$ and a variance of 2. A total of 10,000 signal samples and a sampling frequency of 5,000 Hz were employed.

Figure 2, compares the variance values estimated using various methods. It is observed that the proposed method demonstrates better performance in estimating noise variance.

Conclusions

This research aims to improve the noise variance estimation. To achieve this, the signal is decomposed into various sub-components using the EMD method; subsequently, by estimating the noise energy within these sub-components and calculating their correlation with the noise, a relation along with specific coefficients is derived to estimate the noise variance for each sub-component. The final noise variance value is then calculated by combining these estimates. The proposed method achieves better error reductions compared to the baseline methods. Furthermore, the method demonstrates robust accuracy across varying noise variance levels, frequencies, and Signal-to-Noise Ratios. In summary, the advantages of this approach include its flexibility regarding different signal types, improved accuracy, and reduced computational load achieved by utilizing only P decomposition layers for the variance estimation.

4. References

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