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EEG signal enhancement using cascaded S-Golay filter

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ABSTRACT

Electroencephalogram (EEG) is the most popular signal used for diagnosis of brain disorders. A good quality EEG signal provides the proper interpretation and identification of physiological and pathological phenomena. However, these recordings are often corrupted by different kinds of noise. As Savitzky Golay smoothing filter (SGSF) preserves the peaks and minimize the signal distortion, its use in cascade may further enhance this capability. Therefore in the present work cascaded SGSF (CSGSF) is proposed to filter the noisy EEG signals. The CSGSF combines two successive Savitzky Golay filters. For comparative analysis, other cascaded arrangements like cascaded moving average filter (CMAF), MAF-SGSF, SGSF-Binomial and single stage SGSF are also designed. These filters are tested on artificial EEG signals added with white Gaussian noise and non Gaussian noise. These filters are also tested on real time EEG signals. The filtered signals are assessed through signal to noise ratio (SNR), signal to signal plus noise ratio (SSNR), SNR improvement (SNRI), mean square error (MSE) and correlation coefficient (COR). It is revealed from the results that CSGSF outperforms the other designed filters in case of artificial and real time EEG signals.

1. Introduction

Electroencephalogram (EEG) is a non-invasive diagnostic tool used to detect brain diseases. As EEG is the most widely used signal for the purpose of clinical diagnosis and monitoring, it is very important to use reliable signals. The diseases can be detected quite efficiently with the help of high quality EEG signal. The diagnostic applications often concentrate on the frequency content of these signals. Neurologists interpret these signals but there are few instants (as in intensive care units, ICU or for intraoperative monitoring) where real time monitoring and automatic interpretation of the patient's high resolution EEG is vital. In order to facilitate the neurologist for accurate diagnosis unwanted signals have to be removed. Therefore extrication of high-quality EEG waveforms from the background contaminations is an important aspect to be investigated.

The present work focuses on filtering Gaussian and non-Gaussian noises from physiological signals. These signals are also corrupted with other types of noise which include power line interference, biological origin artefacts like ocular, ECG, muscle activity etc. The signals are also spoiled by artifacts from dialysis machine, cooling blankets, pacemakers, chest percussion, vibrating beds and IV drips [1,2] in ICUs and are out of scope of the present research work. In order to extract clinically relevant features for correct diagnosis of diseases [3–6] from these contaminated signals, it becomes pre-requisite to enhance signal quality. Enhanced signal quality in an ICU can prevent false alarms by correct detection of onsets which is highly dependent on reliable information represented by signal [7–10]. As per recommendations a significant attempt is made to improve the signal quality of recorded EEG signals [11]. The objective of enhancing brain signal is to segregate the genuine signal components from unwanted signals and to obtain an EEG that provides simple and precise interpretation. Therefore a wise use of frequency based filtering of the true waveforms of interest, may balance reduction of noise against decreased fidelity [12,13].

The aim of smoothing is to enhance S/N ratio by reducing the noise as much as possible, with the least distortion of true spectral line shape [12]. Various researchers have implemented digital filters for smoothing purpose and significant improvement is observed in the results [14,15]. If EEG pre-processing is not performed carefully then undesired noise may be introduced which lowers the signal to noise ratio [16]. Savitzky and Golay presented a new smoothing technology [17] in which generalized MAF upholds the higher frequency contents. This technology is inferred from least squares fitting of a lower order polynomial to a number of successive points. The line fitting of conventional MAF is replaced by polynomial curve fitting in Savitzky Golay filter (SGF) which allows better filtering in terms of preserving the higher moments

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and the line width. Therefore SGF is important in smoothing the biomedical signals where peak retention is required. The design and frequency response of Savitzky and Golay filtering technology were investigated by Schafer [18]. SG filters can be designed in many ways for various applications. Recently EEG and ECG signals are pre-processed using SGSF giving high quality signal. SG filter is applied for denoising noisy EEG signals [19] in biomedical engineering. SGF characteristics are examined in ECG signal processing applications depending on different parameters [20]. Many other denoising and smoothing techniques are also used in various applications [21–25].

In many applications two stage or cascaded techniques are used for smoothing purpose. In one of the applications of unstructured grids containing multivariate corrupted data are smoothened with the help of cascaded filter using kernel weighted averaging and least square technique [26]. In other work to get the high quality signal cascaded MAF is used as smoothing filter to attenuate the oscillating variations and denoising knee joint vibration signals [27,28]. A cascaded filter is developed to denoise Fourier transform Infrared spectra [29]. A smoothing polynomial filter having cascaded structure is proposed to enhance the SNR and degree of peak preservation in ultrasonic Internal Rotary Inspection System [30].

Efficient pre-processing is one of the mandatory requirements of any biomedical signal processing system to obtain the accurate results [31–34]. Inadequate smoothing has serious effects on filtering performance [35]. Hence the most motivating problem in biomedical signal processing is to extract high resolution EEG signals from noisy measurements. Sharpness of EEG waveform must be retained efficiently during pre-processing. The spectral quality of a signal (signal-to-noise (S/N) ratio) may be improved by increasing filter width or smoothing the signal multiple times [36]. The increase in filter width causes an increase in smoothing action. The large width of filter widens the peaks and reduces the energy resolution of spectrum. It is also suggested in literature that smoothing process with narrow least square polynomial filter [37–39] may be repeated to improve the signal quality. This motivated for the use of SGSF in cascaded configuration so that EEG signal is filtered twice. As peak evaluation is the main objective of EEG signal processing which helps in disease identification, therefore in the present work the filtering efficiency of SGSF is increased by realizing it in cascade so that pure signal can be obtained.

The paper is structured as follows. Section 1 provides introduction and literature survey. Section 2 presents the theory and design methodology used in implementation of Savitzky-Golay filter for cascaded architecture. The experimental results and analysis of the designed filters are demonstrated in Section 3. Limitations are given in section 4 and the work is concluded in Section 5.

2. Method and material

In all signal processing applications [40] signal enhancement is a prerequisite step therefore in the present work CSGSF is suggested for the purpose. The two stage Savitzky-Golay FIR smoothing filter for biomedical signal processing is not proposed yet. The proposed methodology enhances SNR and reduces signal distortion significantly. A comparative analysis of five different configurations i.e. cascaded MAF, SGSF-MAF, SGSF-Binomial, single stage SGSF and cascaded SGSF is carried out for smoothing EEG signals. The designed filters are tested on artificial (reference) and real EEG signals.

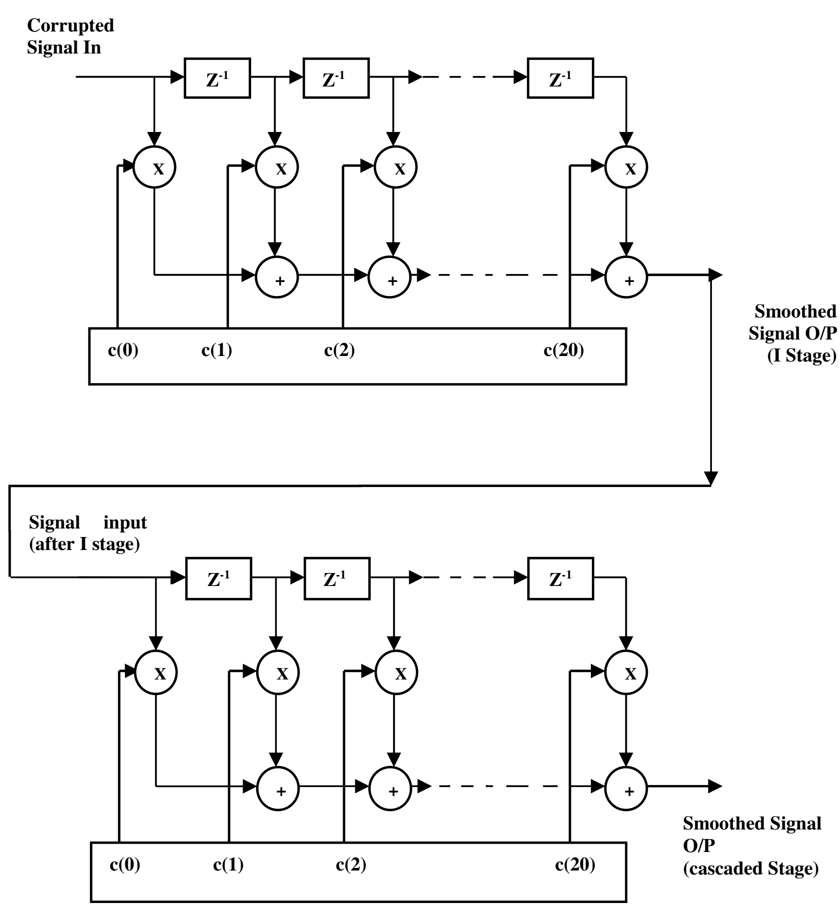

Fig. 1. Cascaded Structure of Savitzky Golay Filter.