Perspectives in Science (2016) 8, 677—679

ScienceDirect

journal homepage: www.elsevier.com/pisc

Application of adaptive Savitzky—Golay filter for EEG signal processing ☆

Deepshikha Acharya*, **Asha Rani**, **Shivangi Agarwal**, **Vijander Singh**

Instrumentation and Control Engineering Division, NSIT, University of Delhi, New Delhi 110078, India

Received 18 February 2016; accepted 9 June 2016
Available online 4 July 2016

KEYWORDS
Adaptive Savitzky—Golay filter;
EEG;
Filtering

Summary A Savitzky—Golay filter typically requires pre-determined values of order and frame size for its fabrication. Generally, a random hit-and-trial method or prior experience is required to determine the suitable values of design parameters. However, the proposed adaptive Savitzky—Golay filter aims to provide a generic framework for optimal design of filter vis-à-vis the order and frame size of the filter. The algorithm uses all the possible combinations of these parameters in a certain range and the correlation coefficient is evaluated in each case to measure the filter efficiency. The parameters which provide the highest correlation coefficient are considered for filter design. In this paper the relative advantages of adaptive Savitzky—Golay filter over the standard models are also discussed. The proposed adaptive model of Savitzky—Golay filter is successfully tested for EEG signal processing.

Introduction

EEG is the most analytic diagnostic technique to assess the electrical activity of brain. These signals consist of artefacts and noise which are filtered out by different types of filters in the pre-processing stage. Numerous signal smoothing algorithms (Agarwal et al., 2016; Li et al., 2015) have been proposed to improve the performance of healthcare devices working in normal environments surrounded with noise. A Savitzky—Golay filter finds extensive use in filtering noise especially in the field of biomedical signal processing. The principle behind SG Filter is to obtain $2n+1$ equidistant points (centred at $n=0$) to represent a polynomial of degree p. SG filter computes the value of the least square polynomial (or its derivative) at point $i=0$, over the entire sample space. Typically, this digital filter uses the technique of linear least squares for data smoothing, which helps to obtain a high signal-to-noise ratio and retains the original shape of the signal.

With its multiple advantages over standard filtering techniques, Savitzky—Golay filter is preferred for retrieving original signal structure while removing noise.

☆ This article belongs to the special issue on Engineering and Material Sciences.

* Corresponding author.
E-mail address: deepshikha.acharya@yahoo.in (D. Acharya).

http://dx.doi.org/10.1016/j.pisc.2016.06.056
2213-0209/

Adaptive SG filter

S—Golay filter is applied to a series of digital data points with the aim of increasing the signal-to-noise ratio without deforming the signal. The subsets of consecutive data points are fitted using a low order polynomial with linear least square method and convolution of all the polynomials is then obtained (Schafer, 2011; Savitzky and Golay, 1964). The data having a set of n $\{x_j, y_j\}$ points, where $j = 1, 2\ldots n$, and x is an independent variable whereas y is an observed value, can be represented with a set of m convolution coefficients, C_i, and given as

$$Y_j = \sum_{i=-(m-1)/2}^{i=(m-1)/2} C_i y_{j+i} \frac{m+1}{2} \leq j \leq n - \frac{m-1}{2}$$

Implementation of SG filter typically requires three inputs: the noisy signal (x), the order of the polynomial (k) and its frame size (f). The best fit values of k and f for a signal are generally estimated using trial and error method. Alternatively the values can also be obtained using prior experience or previously estimated values for a particular level of SNR for the given signal. The proposed 'adaptive' technique (Li et al., 2015) aims to analyse the given signal over a range of order (k) and frame-size (f) values iteratively. The filtered signal is then correlated with the original synthetic signal to find the perfect fit polynomial order and frame size.

Implementation on EEG signal

Electroencephalography finds extensive use in detection of epileptic seizures, studying sleep patterns and depression, to name a few. The signal typically obtained requires an intelligent filter such as the SG filter, utilising iterative least square polynomial fit to ensure that the true structure of the signal is retained, while removing the noise.

Synthetic EEG

A synthetic EEG signal obtained as an arithmetic sum of different sinusoids is used to implement the 'adaptive' S—Golay filtering technique. The design parameters presented by Azami et al. (2014) are used to simulate synthetic EEG signal. The simulation is performed for seven epochs and the signal is used as the base signal for correlation with the filtered signal at a later stage. A white Gaussian noise is added to the synthetic signal with different levels of SNR ranging from 15 to 35 dB.

SG filtering

The S—Golay filter with varying values of frame size and order is applied to the noisy synthetic EEG signal. It is ensured that the order of the polynomial does not exceed the frame size while varying the values iteratively. The polynomial order and frame size are varied from 2 to 10 and 15 to 25 in steps of 2 respectively. The filtered signal is obtained and evaluated over the spectrum of values.

The correlation (COR) between the original synthetic signal and the filtered signal for different values of SNR, frame size and order, helps to evaluate the trend of filtering action for different parameter values.

$$\mathrm{COR} = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(X_i - \overline{X})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2 (X_i - \overline{X})^2}}$$

here dataset $X = \{X_1 \ldots X_n\}$, $\overline{X}$, sample mean, dataset $Y = \{Y_1 \ldots Y_n\}$, $\overline{Y}$, sample mean. The perfect filtering is obtained if correlation between the synthetic signal and S—Golay filtered signal is 1.00 and the corresponding values of frame size and order are optimal.

Advantages of adaptive SG filtering

The primary advantage of SG filter is its capacity to retain shape of the signal, which is generally not possible with a moving average filter (Agarwal et al., 2016; Baijal et al., 2015; Hargittai, 2005). The performance of SG filter is much superior to the conventional filters, if correct frame size and order is chosen. Adaptive SG filtering helps to select the optimal frame size and order using iterative analysis and signal correlation. This helps to eliminate the heuristic aspect, often quoted as a disadvantage, in SG filter. Further the processing speed is increased significantly. The filter coefficients need to be evaluated just once for a given application which makes the filtering process simple, easy and fast. The technique apart from overcoming the drawback of parameter evaluation, allows the use of optimal values to get the best filtered signal.

Results and discussion

The noisy synthetic EEG signal is filtered with the help of adaptive S—Golay filter. The filtered signal and the standard synthetic signal are plotted on the same graph (Fig. 1) for optimal frame size and order at SNR of 35, for comparative analysis. The signals plotted show close correlation for S—Golay filtering and the best fit response is obtained. Table 1 gives the values of frame size, order and correlation for different values of SNR. It is observed that the value of correlation coefficient for all the cases is found to be almost 1, i.e. the filtered signal apart from removing the noise, retains the features of the original signal efficiently. The adaptive S—Golay filtering algorithm can also be applied on real time signals using different databases or on acquired

Table 1 Optimal parameters for different values of SNR.

SNR	Order of the polynomial	Frame size	Correlation
10	2	25	0.9955
15	2	25	0.9986
20	2	21, 23, 25	0.9995
25	2, 4	21, 23, 25	0.9998
30	2, 4	19, 21, 23, 25	0.9999
35	2, 4	17—25	1.0000

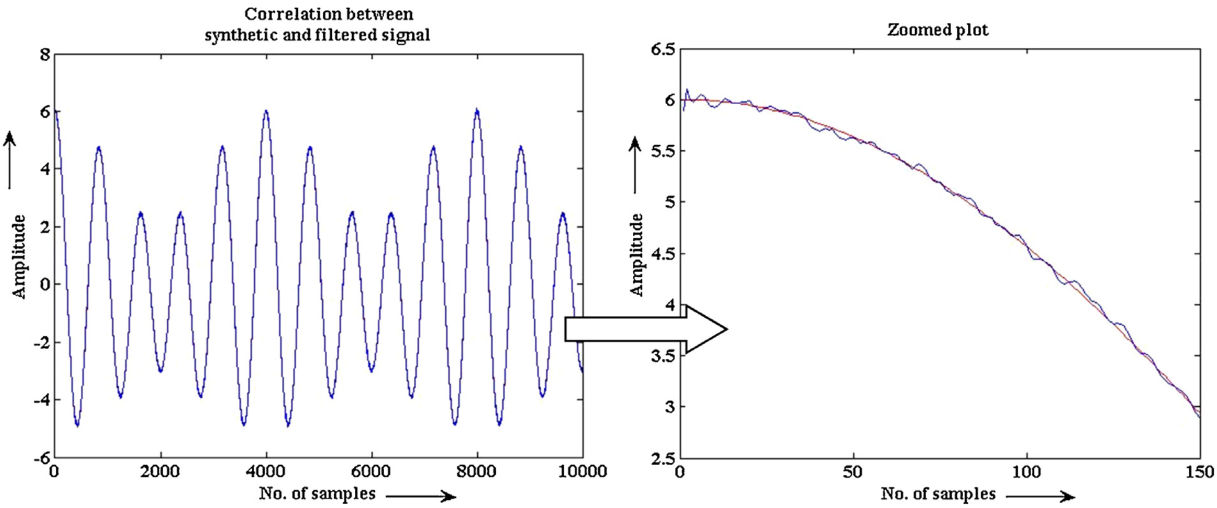

Figure 1 Correlation between the synthetic and filtered EEG signal.

EEG using ADS1299EEG FE module (Acharya et al., 2015). The adaptive SG filtering technique replaces the heuristic or trial and error process of evaluating filter parameters by the iterative and self-evaluative process.

Conclusion

The adaptive SG filter is designed and applied for synthetic EEG signals. The design parameters of the filter are varied in a certain feasible range and all the possible combinations are evaluated using a systematic procedure. The parameters corresponding to the highest correlation coefficient are the optimal design parameters of the filter. The designed filter is tested successfully on noisy synthetic EEG signal for different values of SNR. It is revealed that the adaptive SG filter removes the noise as well as the original shape of the signal is maintained. The technique proves to be computationally simple, fast and efficient. Further the method can also be used for other signals such as ECG, EMG, EOG, and EGG.

Acknowledgements

We would like to thank the Biomedical Research Lab, ICE Division at NSIT, Delhi University for all the facilities provided and the encouragement and guidance given during the project work.

References

Acharya, D., Rani, A., Agarwal, S., EEG data acquisition circuit system based on ADS1299EEG FE 2015. 4th International Conference on Reliability, Infocom Technologies and Optimization (ICRITO) (Trends and Future Directions) , 2—4 September, 2015, pp. 1—5.

Agarwal, S., Rani, A., Singh, V., Mittal, A.P., 2016. Performance evaluation and FPGA based implementation of SGSF in smart diagnostic applications. J. Med. Syst. 40 (3), 63, http://dx.doi.org/10.1007/s10916-015-0404-2.

Azami, H., Saraf, M., Mohammadi, K., 2014, September. A new signal segmentation approach based on singular value decomposition and intelligent Savitzky—Golay filter. In: Artificial Intelligence and Signal Processing. Communications in Computer and Information Science, vol. 427., pp. 212—224.

Baijal, S., Singh, S., Rani, A., Agarwal, S., 2015, December. Performance evaluation of S-Golay and MA filter on the basis of white and flicker noise. In: Advances in Signal Processing and Intelligent Recognition Systems. Advances in Intelligent Systems and Computing, vol. 425., pp. 245—255.

Hargittai, S., 2005. Savitzky—Golay least-squares polynomial filters in ECG signal processing. Comput. Cardiol. 32, 763—766.

Li, J., Deng, H., Li, P., Yu, B., 2015. Real-time infrared gas detection based on an adaptive Savitzky—Golay algorithm. Appl. Phys. B: Lasers Opt. 120, 207—216.

Savitzky, A., Golay, M.J.E., 1964. Smoothing and differentiation of data by simplified least squares procedures. Anal. Chem. 36, 1627—1639.

Schafer, R., 2011. What is a Savitzky—Golay filter? IEEE Signal Process. Mag. 28, 111—117 (Lecture Notes).