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# An automatic de-noising and smoothing method for surface electromyography signals based on singular spectrum analysis

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## Introduction

An automatic heuristic procedure which applies singular spectrum analysis (SSA) and cluster analysis to automatically de-noise and smooth surface electromyography (sEMG) signals is presented.

## Materials and methods

The proposed approach constitutes an alternative to the traditional smoothing procedures such as moving average (MOVAG), RMS, or low-pass Butterworth filtering[1] used to extract the trend of the signal. SSA is a non-parametric technique that decomposes the original time series into a set of additive time series in which the noise present in the acquired signal can be easily identified. The SSA method constructs a Hankel matrix called the trajectory matrix from the original time series in a process called embedding. This matrix consists of vectors obtained by means of a sliding window that traverses the time series. The trajectory matrix is then subjected to singular value decomposition (SVD). The result is a sum of rank-one matrices known as elementary matrices. The contribution of the first elementary matrices to the norm of the decomposition is much greater than that of the last matrices. Therefore, it is likely that these last matrices represent noise in the signal (Fig.1a). These elementary matrices are no longer Hankel matrices, but an approximate time series may be recovered by taking the average of the diagonals (diagonal averaging). The resulting time series are called principal components[2], with the original time series being the sum of all these principal components. The objective is to obtain a frequency decomposition of the original signal from which the latent low-frequency signal (sEMG) can be detected and isolated[2]. The obtained results depend on the selected window length, *L*. To automate the process, once selected the window length, a k-means clustering (*k=3-5*) is applied to the w-correlation matrix (Fig.1b). The signal is reconstructed from the obtained cluster whose rms error with the sEMG signal is smallest. Then, sequential SSA is applied to the reconstructed signal to gradually eliminate the noise. From the de-noised signal, the trend or smoothed signal ($S_i$) is obtained by reconstructing the signal from the components ($G_i$) whose mean eigenvalue ($\hat{\lambda}_i$) is above the rms value:

$$S_i = \sum_i G_i \;\; / \;\; \hat{\lambda}_i > rms(\hat{\lambda}_1, \hat{\lambda}_2, \dots, \hat{\lambda}_L)$$

where $\hat{\lambda}_i = \frac{\lambda_i}{\sum_{i=1}^{L} \lambda_i}$.

To assess the quality of the method, the results of its application to a non-stationary sEMG signal are compared with those of other step-wise filtering and smoothing techniques.

## Results and discussion

The results of the automatic de-noising method were compared with the recommended Butterworth passband filter (10-450 Hz). Root-mean-square error between rectified raw signal and the de-noised one were calculated. Results were $1.0557 \cdot 10^{-2}$mV for the Butterworth filter and $0.9532 \cdot 10^{-2}$mV for the SSA algorithm. The results of the smoothing step (Fig.2) show the accuracy of the method compared against recommended smoothing procedures. Further experiments are required to automate the number of clusters, however, the approach has proved itself to be a reasonable alternative to the traditional de-noising methods.

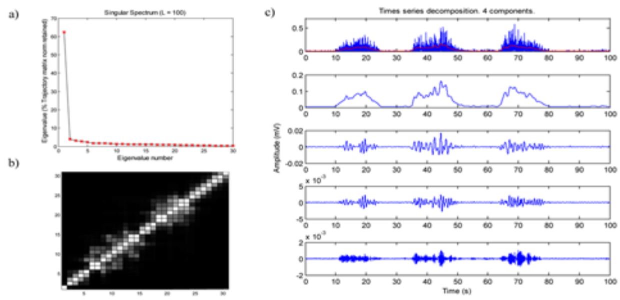

*Fig. 1: a) Singular spectrum. b) W-correlation matrix. c) top: original and filtered signal, bottom: signal decomposition.*

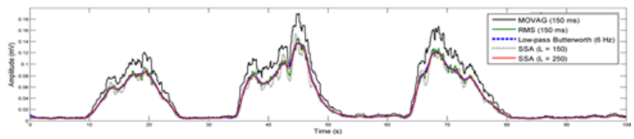

*Fig. 2: Smoothed signals: low-pass butterworth (6 Hz), rms (150 ms), MOVAG, (150 ms) and SSA (L=150 and L=250).*

## Conclusion

The proposed heuristic method allows an automatic elimination of the noise present in the sEMG signal. Besides, the method also allows to smooth the signal to extract the trend. Results may contribute to improving the accuracy of the processing and analysis of the complex signals acquired in sEMG.

## Acknowledgements

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## References

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