

On the Optimal Choice of Wavelet Stages in “Motion Artifact Removal in ECG Signals Using Multi-Resolution Thresholding”

This article contains additional information concerning the parameter choice of the paper by Strasser et al. [1]. Based on an extensive simulation and real-data evaluation, we suggest a default setting for the number of wavelet stages used in the algorithm. The number of stages depends on the sampling frequency (f_s) used in the ECG measurements. When M is chosen too small for a given f_s , the complexity of the ECG is not accounted in the signal reconstruction stage. Choosing M too large is not as critical, however it leads to high MSE in the signal reconstruction. Furthermore, computational costs are higher.

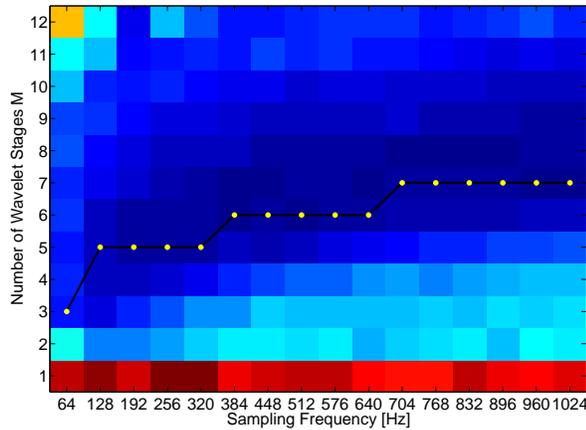


Fig. 1: Decision map showing the optimal number of wavelet stages M for a range of sampling frequencies.

Therefore, we suggest a default setting with M ranging from 3 to 7 as shown in Figure 1. Figure 1 plots the mean MSE for the signal reconstruction for a large variety of synthesized data with varying ECG and artifact parameters.

$$\text{MSE} = \frac{1}{N_{\text{mc}}} \sum_1^{N_{\text{mc}}} (\text{ECG}_{\text{true}} - \widehat{\text{ECG}}_{\text{cleaned}})$$

Real data evaluation with clean ECG signals and real motion artifacts from the MIT-BIH Arrhythmia Database gave similar results.

For $f_s > 1024$, $M > 7$ does not give a significant gain in MSE. Figure 2 shows an example of the mean MSE at $f_s = 1024$. It is thus an excerpt of Figure 1. It can be seen that the MSE is minimized for $M = 7$ stages.

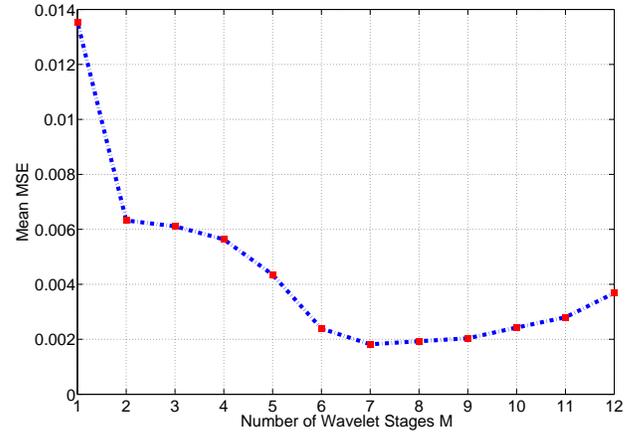


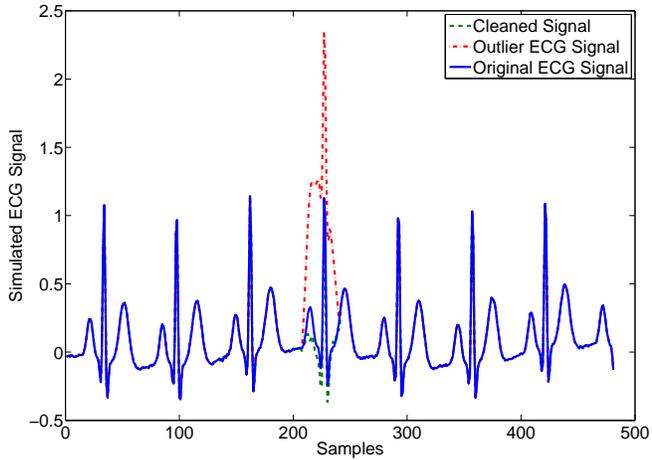
Fig. 2: Mean MSE depending on the number of wavelet stages M for $f_s = 1024$.

Figure 3 and Figure 4 show an illustrative example of a 7.5 seconds ECG measurement with manually added artifacts, sampled at two different f_s . In both cases $M = 3, 5,$ and 7 is used, and resulting cleaned signals are displayed. The subjective visual impression resembles the overall results obtained in our studies. The algorithm described in [1] combined with this additional parameter setting now allows for a fully automated ECG cleaning, irrespective of any signal parameters such as the sampling frequency, SNR, and measurement equipment of subject.

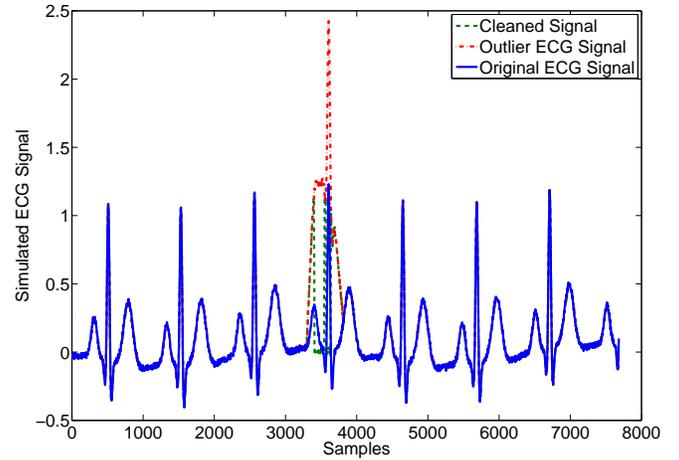
The MATLAB code containing this method can be freely downloaded at <http://www.spg.tu-darmstadt.de/res/dl/index.en.jsp>

REFERENCES

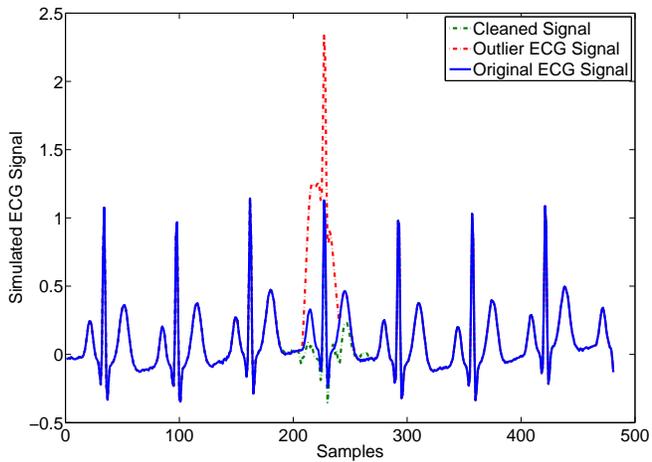
- [1] F. Strasser, M. Muma, and A. M. Zoubir, “Motion Artifact Removal in ECG Signals Using Multi-Resolution Thresholding,” European Signal Processing Conference (EUSIPCO) 2012 in Bucharest, Romania, pages 899-903, August 2012.



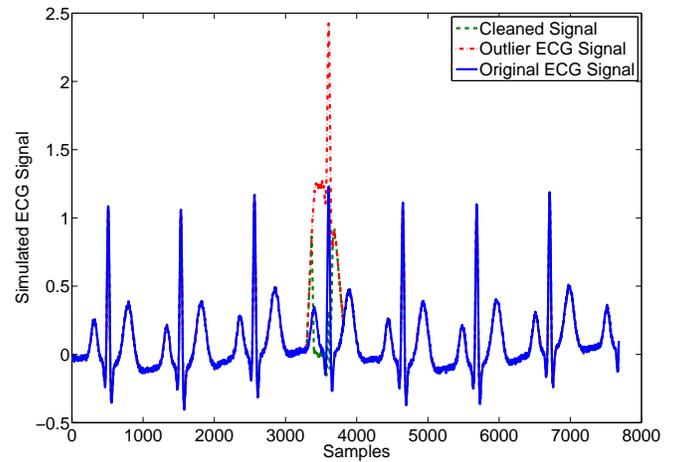
(a) $M = 3$



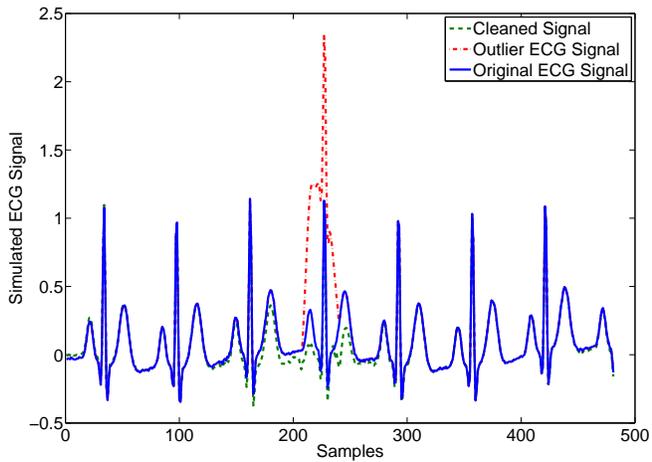
(a) $M = 3$



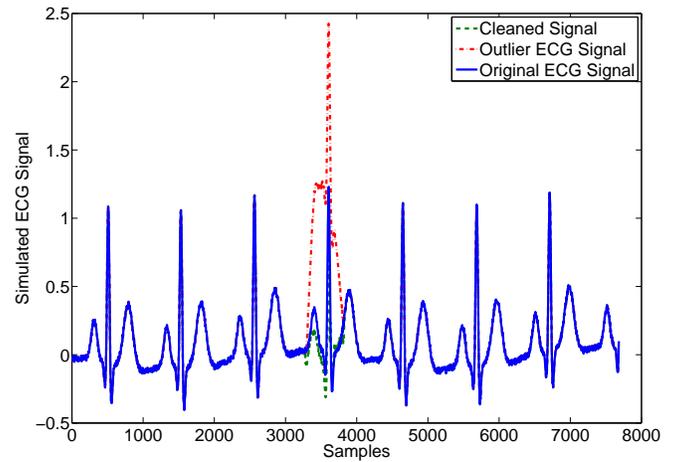
(b) $M = 5$



(b) $M = 5$



(c) $M = 7$



(c) $M = 7$

Fig. 3: Artifact cancellation with $f_s = 64$ Hz, where the initially captured ECG signal is labelled as *Original ECG Signal*, *Outlier ECG Signal* represents *Original ECG Signal* with outliers, and the signal resulted after applying the algorithm is named *Cleaned Signal*. Best result is obtained for $M = 3$.

Fig. 4: Artifact cancellation with $f_s = 1024$ Hz, where the initially captured ECG signal is labelled as *Original ECG Signal*, *Outlier ECG Signal* represents *Original ECG Signal* with outliers, and the signal resulted after applying the algorithm is named *Cleaned Signal*. Best result is obtained for $M = 7$.