ECSA-8
The 8th International Electronic Conference on Sensors and Applications
01–15 NOVEMBER 2021 | ONLINE

“Removal of ECG baseline wander when recorded by a 24-bit ADC using a resting cycle template”

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1/Nov/2021

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PROBLEM STATEMENT

- ✓ Electrocardiogram (ECG) provides information about heart electrical behavior. Wearable sensors allow detection to be done during physical activity. However, a raw signal might not be useful when noise affects the contained information.

- ✓ ECG is susceptible to noise from different sources including movement. A common type of noise induced by movement is baseline wander (BW).

- ✓ BW is a low-frequency artifact. Therefore, the usage of high-pass filters is a widely applied method to remove BW from a signal. However, they might remove useful low-frequency information, as well as depress the P and T waves; therefore, other methods to remove BW are preferred.

- ✓ Denoising an ECG signal represents a challenge when the monitoring is made during physical activity.

BACKGROUND

- Some methods to denoise ECG look to replicate the BW trend to subtract it from the raw signal.
- Some methods to replicate the BW trend include spline interpolation, whose accuracy increases as the number of interpolated points increases.
- With a methodology for a rapid prototyping of an ECG device, motion artifacts inherent in mobile health devices, as the ones occurring from wearable ECG sensors, were previously studied using high-resolution measure devices

PROJECT OBJECTIVES

General Objetive:

- The objective of this present work was to use the rapid prototyping platform to identify a new method to replicate the BW trend using an ECG rest cycle template and compare it with a high-pass filter and a spline interpolation methods; as a consideration of processing a noisy signal acquired by a high-resolution (24 bits) wearable system.

MATERIALS AND METHODS

High-resolution system

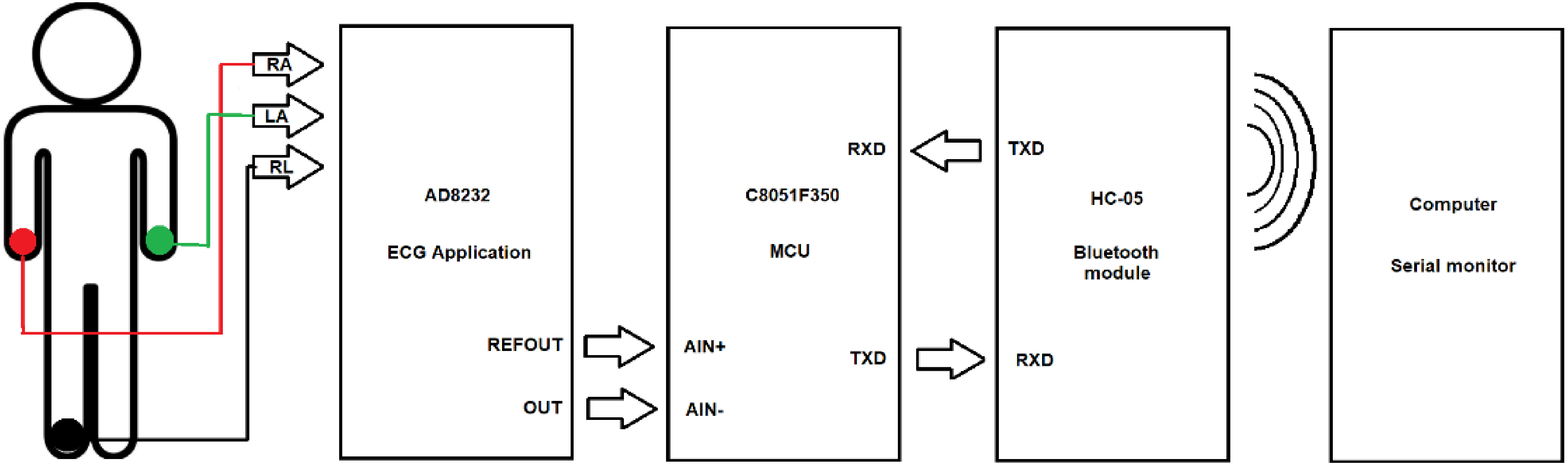

Figure 1. block diagram of high-resolution rapid prototyping platform for wearable devices.

MATERIALS AND METHODS

Test subject specifications:

- Healthy male
- **Height:** 177cm
- **Age**: 23
- **Weight**: 61Kg
- **Heart electrical axis**: 120 degrees
- **Registered lead**: DII (IN+ on right arm, IN- on left leg, reference on right leg.

The test subject did a stationary gait with sudden movement during the signal recording to induce BW.

MATERIALS AND METHODS

Recorded signal

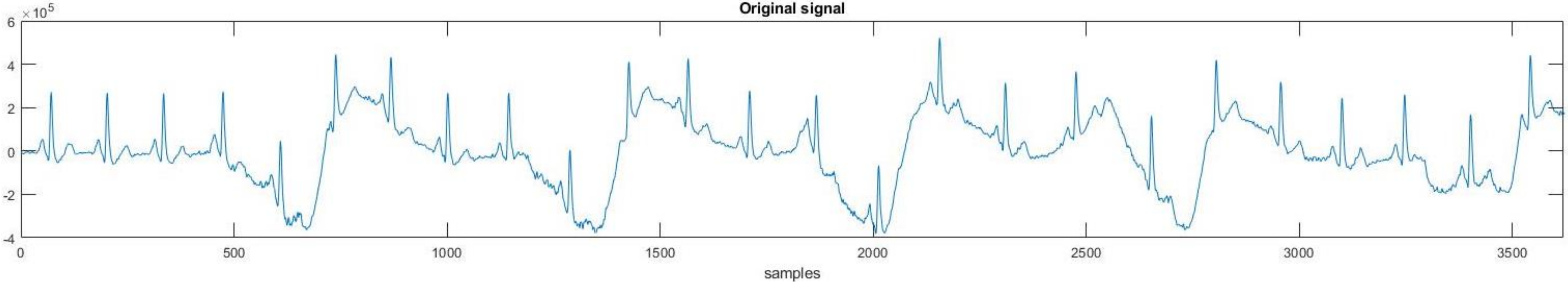

Figure 2. Original recorded signal.

SIGNAL PROCESSING

Method 1. Second-order high-pass butterworth filter

Cut frequency: 1Hz
The filter was designed with the MATLAB “filter design tool” application.

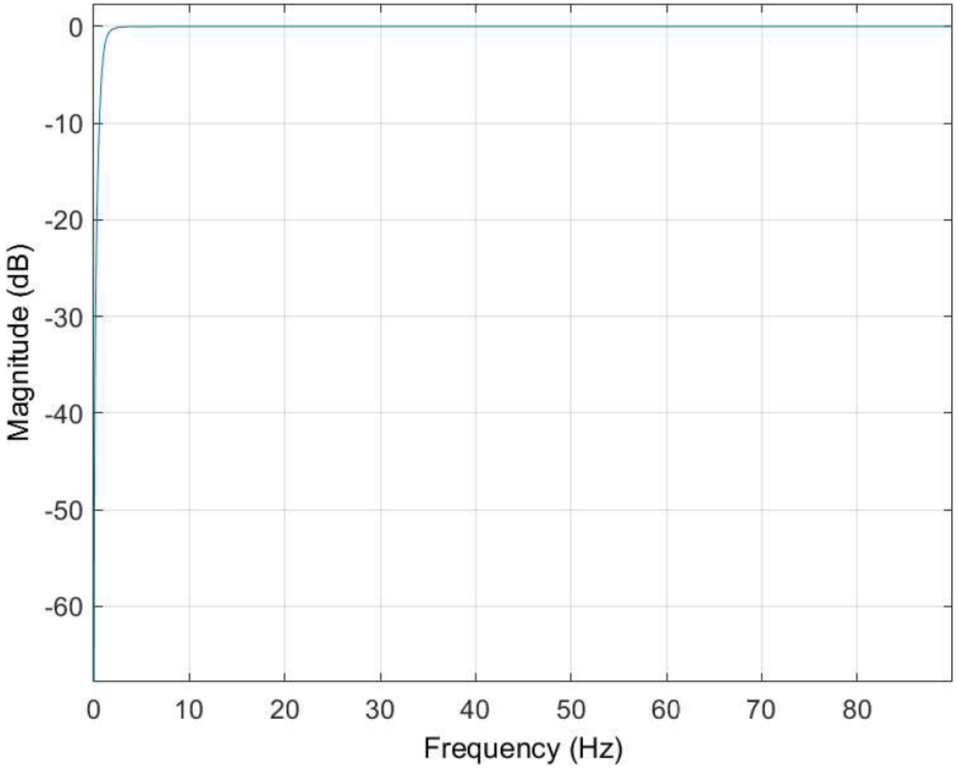

Figure 3. Magnitude response of filter.

SIGNAL PROCESSING

Method 2. Spline interpolation

a)

b)

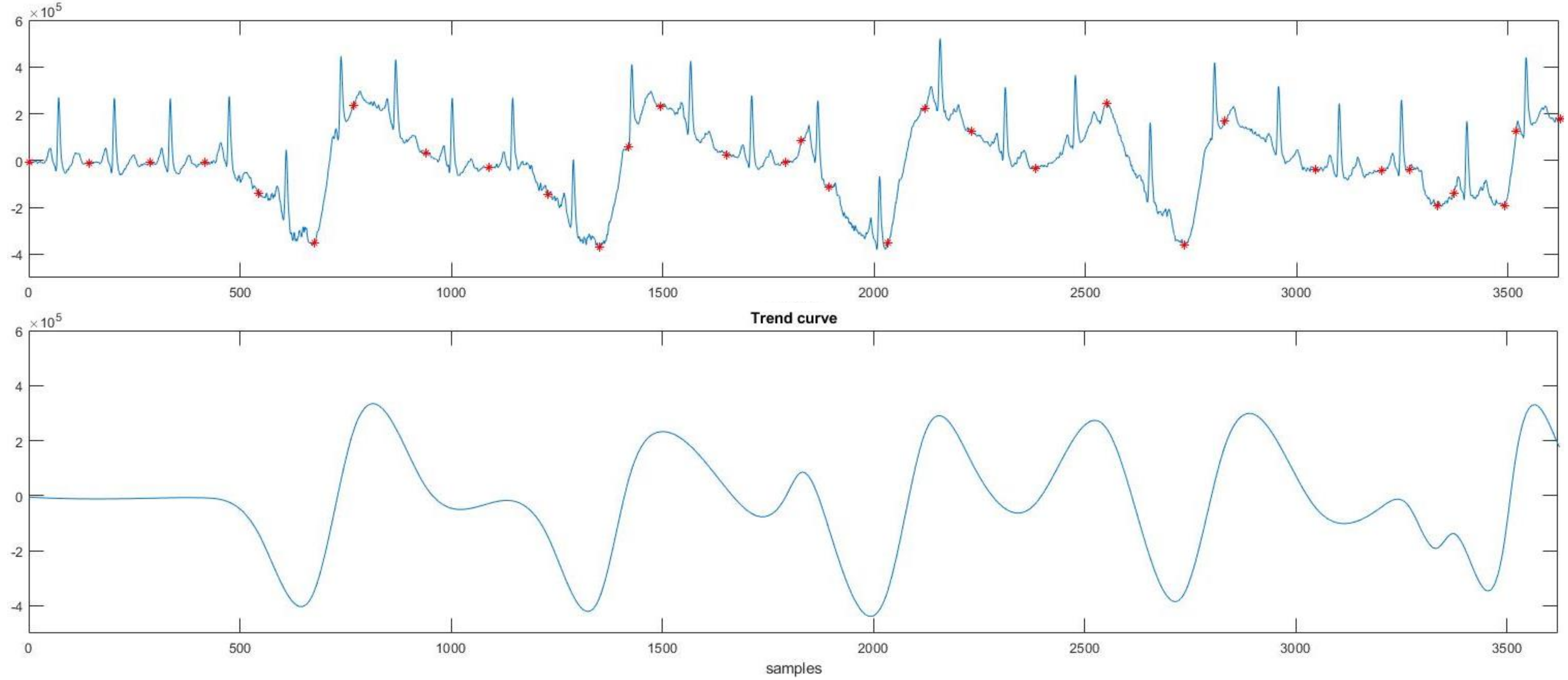

Figure 4. Spline interpolation. a) Interpolated points. b) generated trend curve.

SIGNAL PROCESSING

Method 3. Using an ECG rest cycle template

To design this method, it is assumed that once the BW is removed, every ECG wave shape during the recording was equal in the signal. Therefore, an ECG wave during resting position when no BW was present was used as a template to build an expected signal (ES).

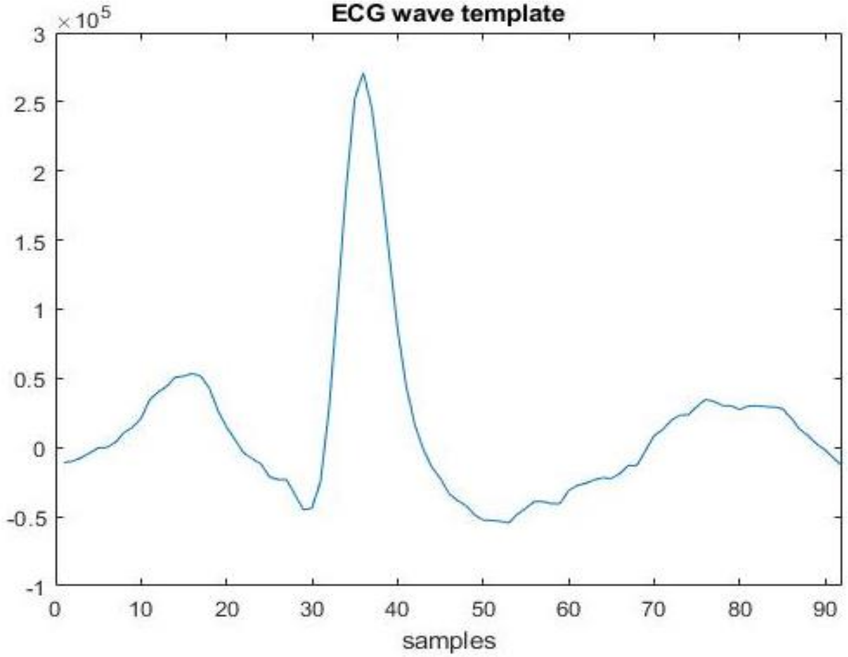

Figure 5. ECG rest cycle wave template.

SIGNAL PROCESSING

Method 3. Using an ECG rest cycle template

The desired signal was built by placing the template along a vector in the same positions where every ECG wave in the original signal is present, being centered by the R peak (highest value) of the wave. The R peaks were manually detected now but for future implementation there are several automated algorithms that can achieve the peak detection.

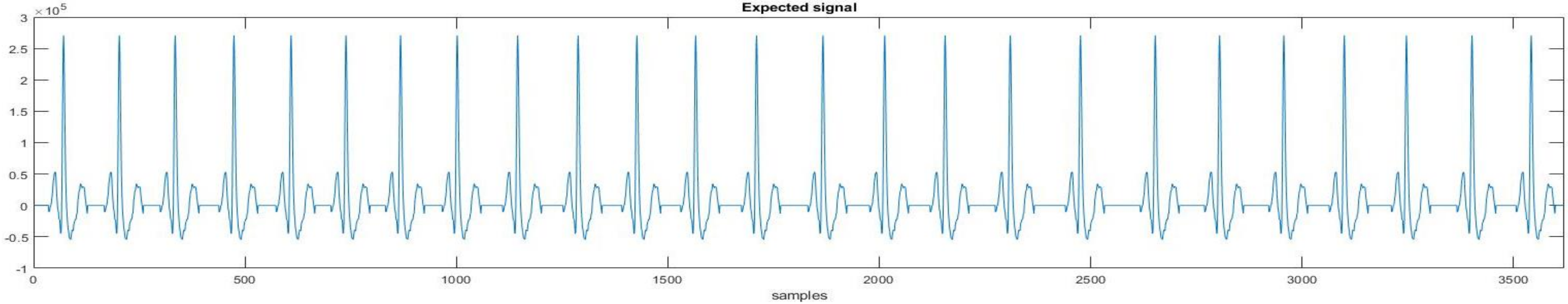

Figure 6. Expected signal.

SIGNAL PROCESSING

Method 3. Using an ECG rest cycle template

The desired signal was built by placing the template along a vector in the same positions where every ECG wave in the original signal is present, being centered by the R peak (highest value) of the wave. The R peaks were manually detected now but for future implementation there are several automated algorithms that can achieve the peak detection.

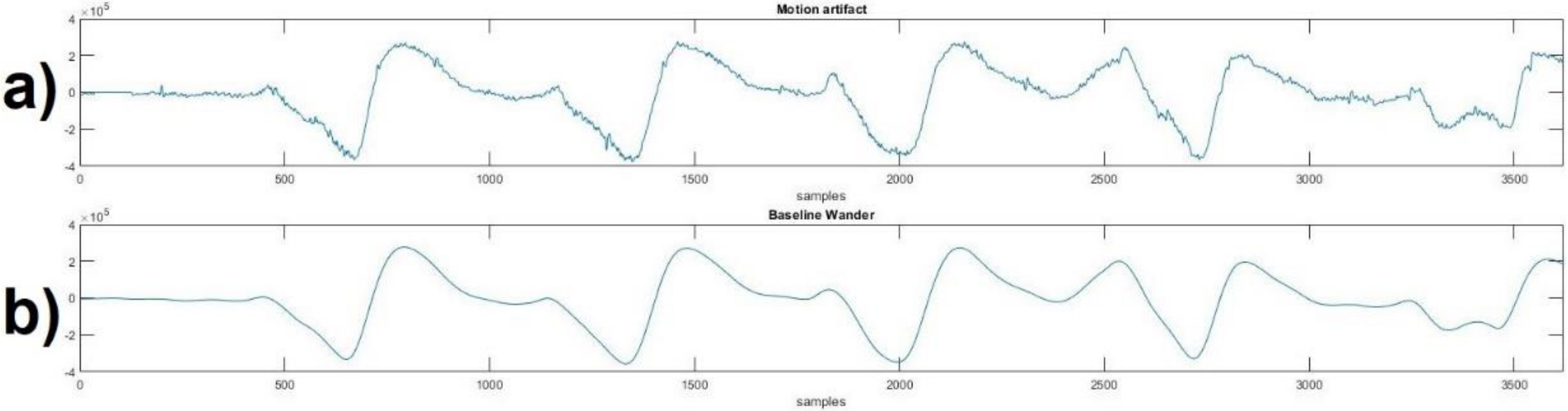

Figure 7. a) Motion artifact after subtraction of expected signal (template train) to the original signal. b) Baseline Wander.

RESULTS

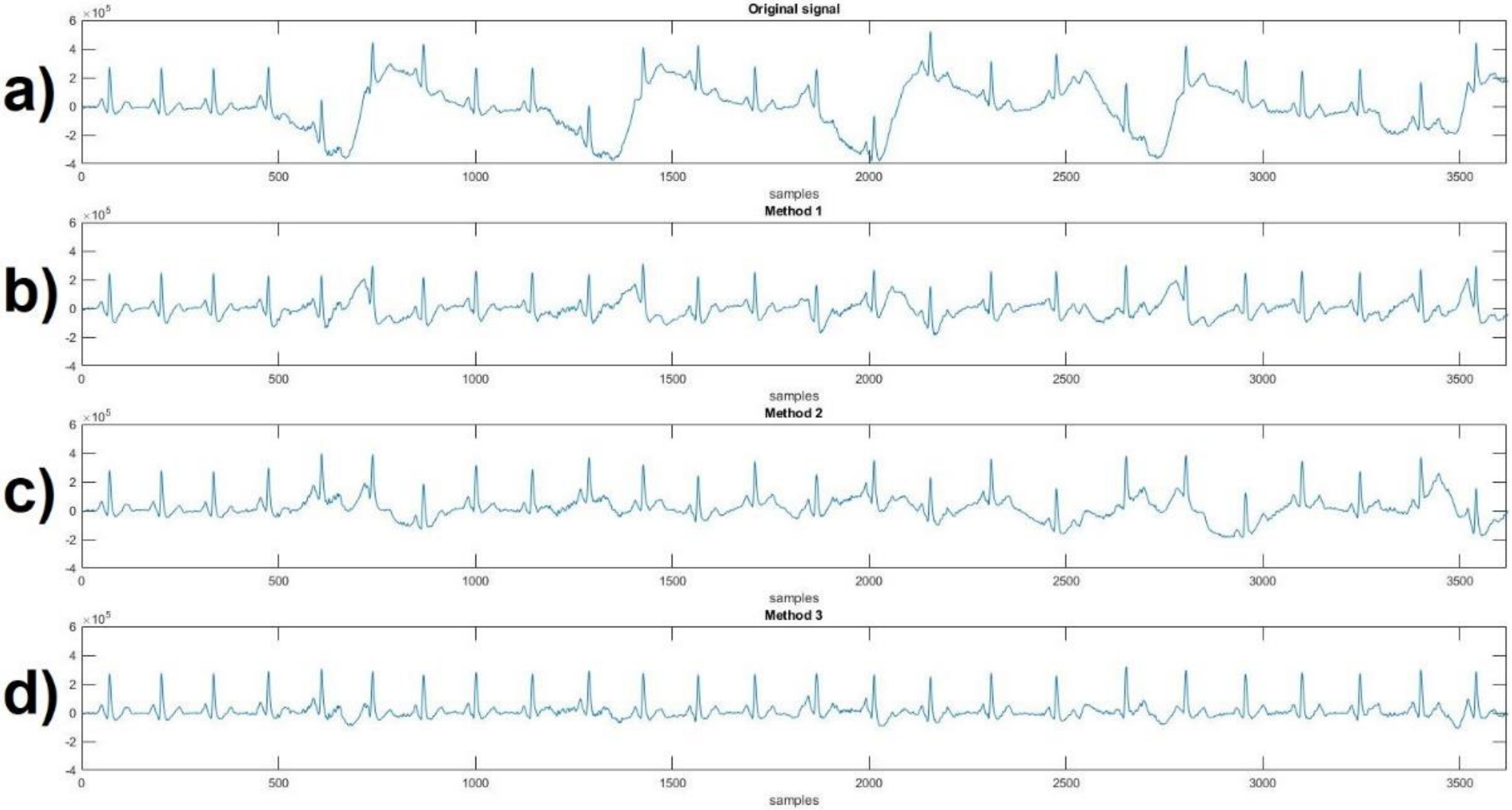

Figure 8. a) Resulting signals comparison with original signal. a) Original Signal. b) Method 1 result-12 ing signal. c) Method 2 resulting signal. d) Method 3 resulting signal.

RESULTS

Method	RMS	σ	RMS ratio	σ ratio	RMS attenuation (dB)	σ attenuation(dB)
Original signal	160230	160238	1.00	1.00	0.00	0.00
High-pass filter	81722	71643	0.51	0.45	-2.92	-3.50
Spline interpolation	87154	84682	0.54	0.53	-2.64	-2.77
ECG cycle as template	59670	58629	0.37	0.37	-4.29	-4.37

Table 1. This table shows the comparison between each method described in this work. The RMS value and standard deviation (σ) of each processed signal are compared with the RMS value and standard deviation (σ) of the original signal. The attenuation that each method provides is shown.

RESULTS

- As observed on Table 1. Using an ECG rest cycle (method 3) as template to remove BW from a noisy ECG signal provides a higher attenuation of the BW than applying a second-order high-pass butterworth filter, as well as it provides a higher attenuation than using a generated trend curve by spline interpolation to remove BW.

- A more accurate trend curve could be generated if more points from the original signal are used. However, since the points are limited to sections of isoelectric potential where no ECG waves are present, BW would not be completely removed. Using a secondorder butterworth high-pass filter provides a higher attenuation of BW than using spline 4 interpolation.

CONCLUSIONS

- The usage of wearable devices to record an ECG signal from a patient in daily activities can easily corrupt the signal of interest with motion artifacts. However, with adequate post-processing, a smooth and useful ECG signal can be achieved by removing the BW, as the method of ECG rest cycle template presented.The high-resolution (24-bits) silicon labs platform showed a higher susceptibility to RMS input noise as sampling rate increases (see table 2 and figure 4).

- This wearable device method required a high-resolution 24-bit ADC and a low gain AD8232 analog input, together with the capability for the patient to set a resting moment.

- The usage of a QRS peak detector is recommended to automate the build of the expected signal, which is the key to correctly stablish the motion artifacts.