ECG signal conditioning by morphological filtering

Biomedical Signal Processing – Unimi

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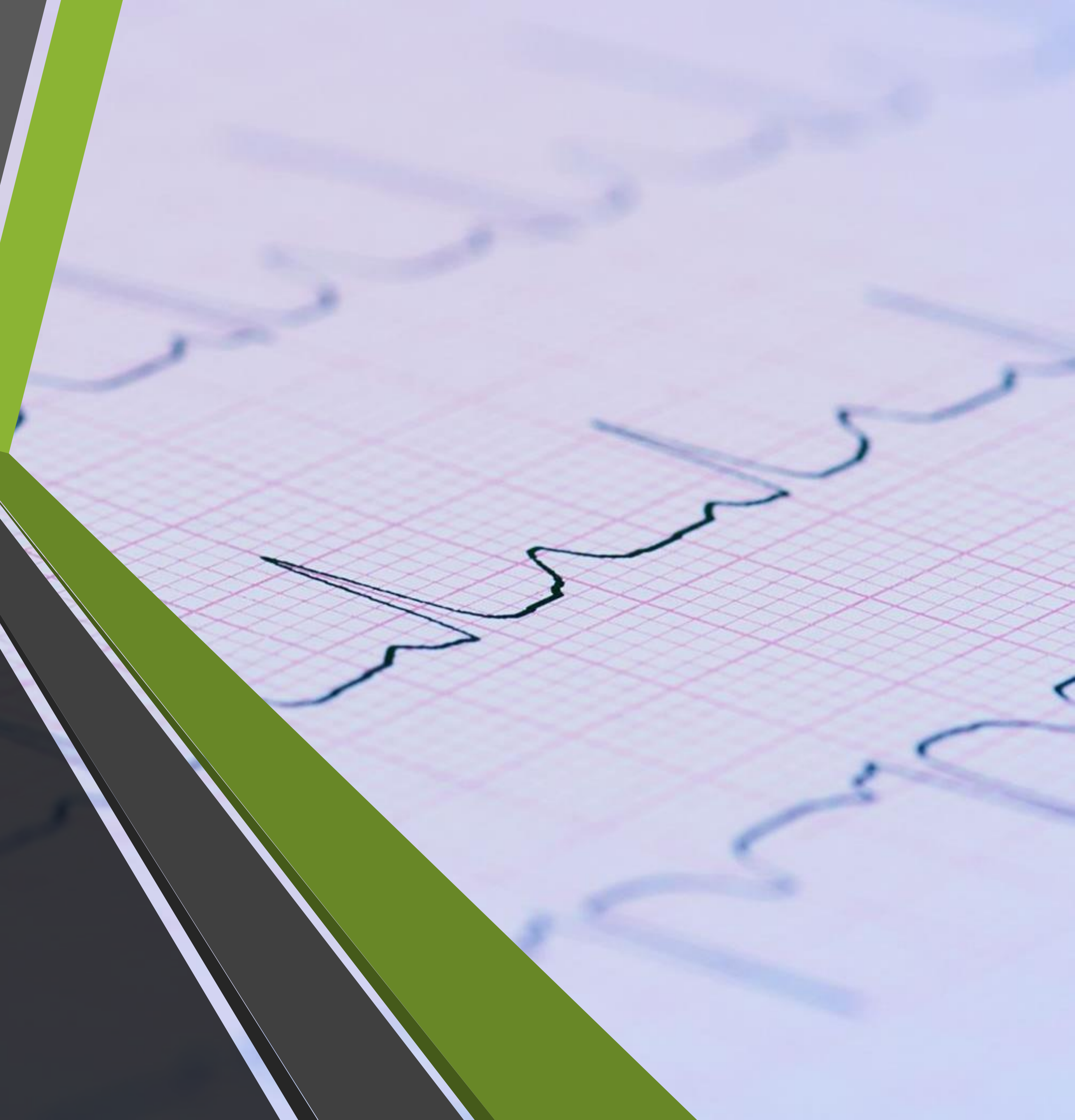


Introduction

- Clinically obtained electrocardiographic (ECG) signals are often contaminated with different types of noise and baseline drifting commonly occurs.
- A modified morphological filtering (MMF) technique is used for signal conditioning in order to accomplish baseline correction and noise suppression with minimum signal distortion.

Mathematical Morphology

Mathematical morphology (MM) provides an approach to the development of non-linear signal processing methods.

The shape information of a signal can be extracted by using a structuring element to operate on the signal.

There are two basic morphological operators:

Erosion:
removes pixels on object boundaries.

Dilation:
adds pixels on the object boundaries.

Erosion:

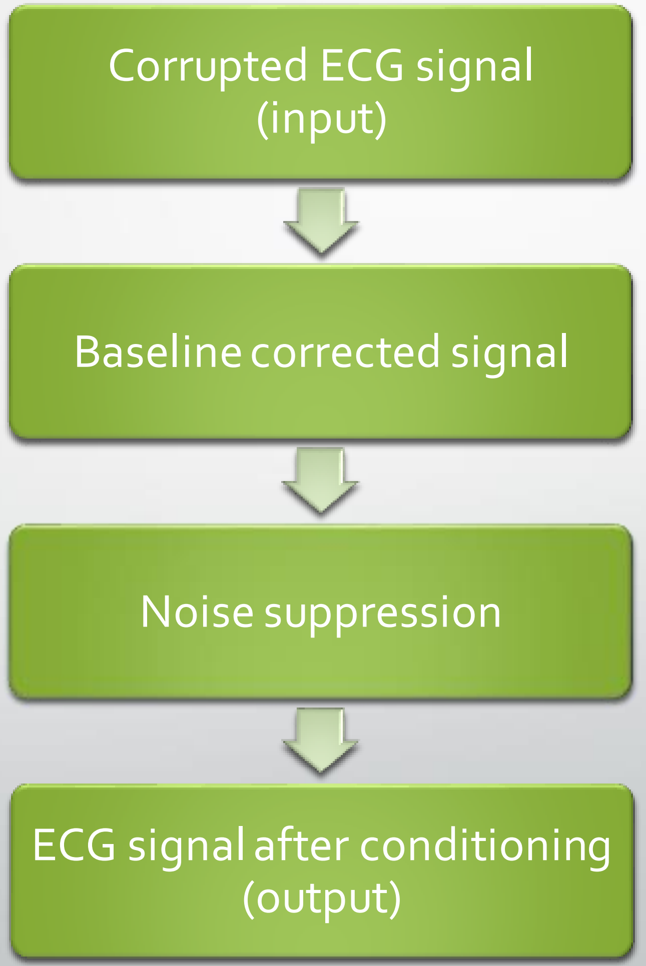
$$(f \ominus B)(n) = \min_{m=0,\ldots,M-1} \left\{ f\left(n - \frac{M-1}{2} + m\right) - B(m) \right\}$$

Dilation:

$$(f \oplus B)(n) = \max_{m=0,\ldots,M-1} \left\{ f\left(n - \frac{M-1}{2} + m\right) + B(m) \right\}$$

$$\text{for } n = \left\{ \frac{M-1}{2}, \ldots, N - \frac{M+1}{2} \right\}$$

Proposed MMF algorithm for ECG signal conditioning



Algorithm testing using simulated data

- The performance of the algorithm could be evaluated by starting with a known signal, corrupting it by adding noise and baseline drift.

- Noise is modelled by a mixture of Gaussian noise.
- Baseline drift is simulated by adding a slanted line to a sinusoidal signal.

Data extraction

The ECG signals were extracted from MIT–BIH arrhythmia database (physionet.org)

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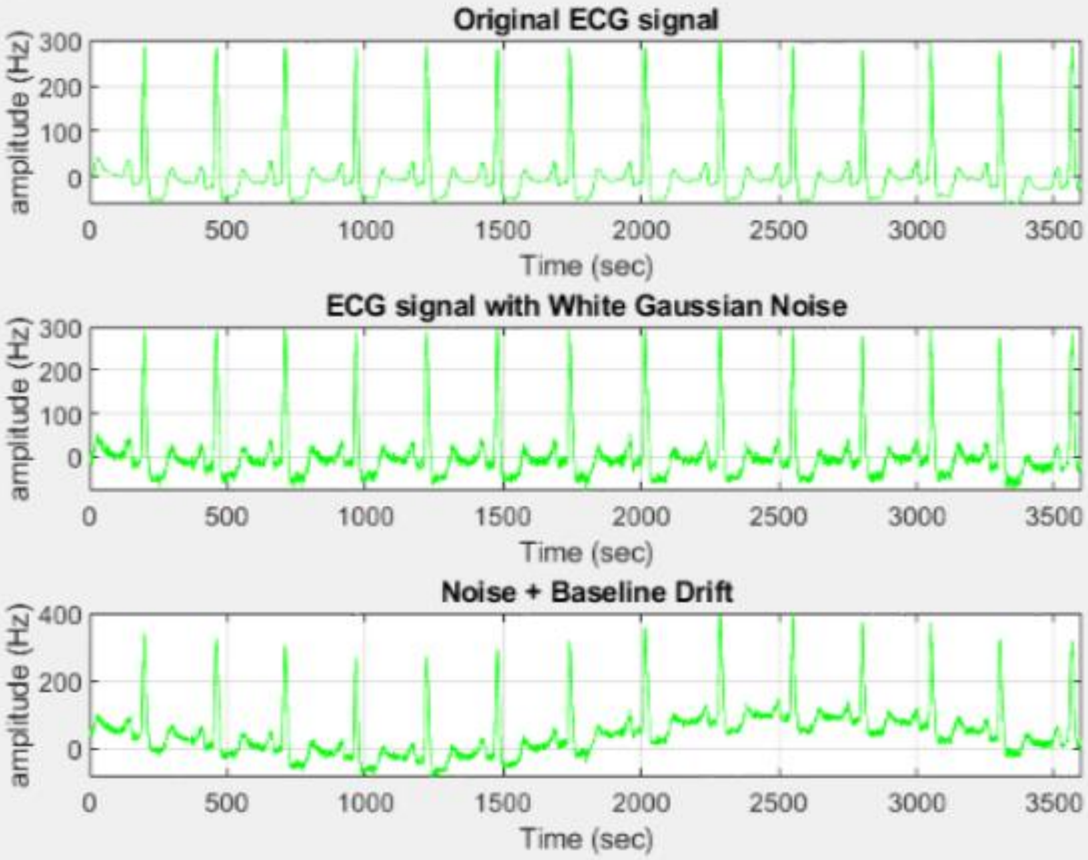
Butterworth Filter

- Before corrupting the ECG signal, we need to make sure it is clean. It can be done by using a lowpass filter.
- The Butterworth filter is a type of signal processing filter designed to have a frequency response that is as flat as possible in the passband.

Signal corrupted by adding noise and baseline drift

$$N(n) = (1-\varepsilon)G_1\left(\frac{n}{\sigma_1}\right) + \varepsilon G_2\left(\frac{n}{\sigma_2}\right)$$

$$B(n) = B + mn + A\cos\left(2\pi\frac{n}{N} + \phi\right)$$



Baseline correction

- The correction of baseline is performed by removing the drift in background from the original ECG signal.
- It follows Chu's method

The signal is first opened by a structuring element *Bo* for removing peaks in the signal.

Than the resultant waveforms with pits are removed by a closing operation using the other structuring element *Bc*.

The final result is then an estimate of the baseline drift *fb*.

The correction of the baseline is then done by subtracting *fb* from the original signal *fo*.

Bo and Bc are selected as two horizontal line segments of zero amplitude, but with different lengths

Noise suppression

- After baseline correction, noise suppression is performed by processing the data through an opening and a closing operation concurrently.
- Then the results are averaged.

Erosion + Dilation = Opening operation

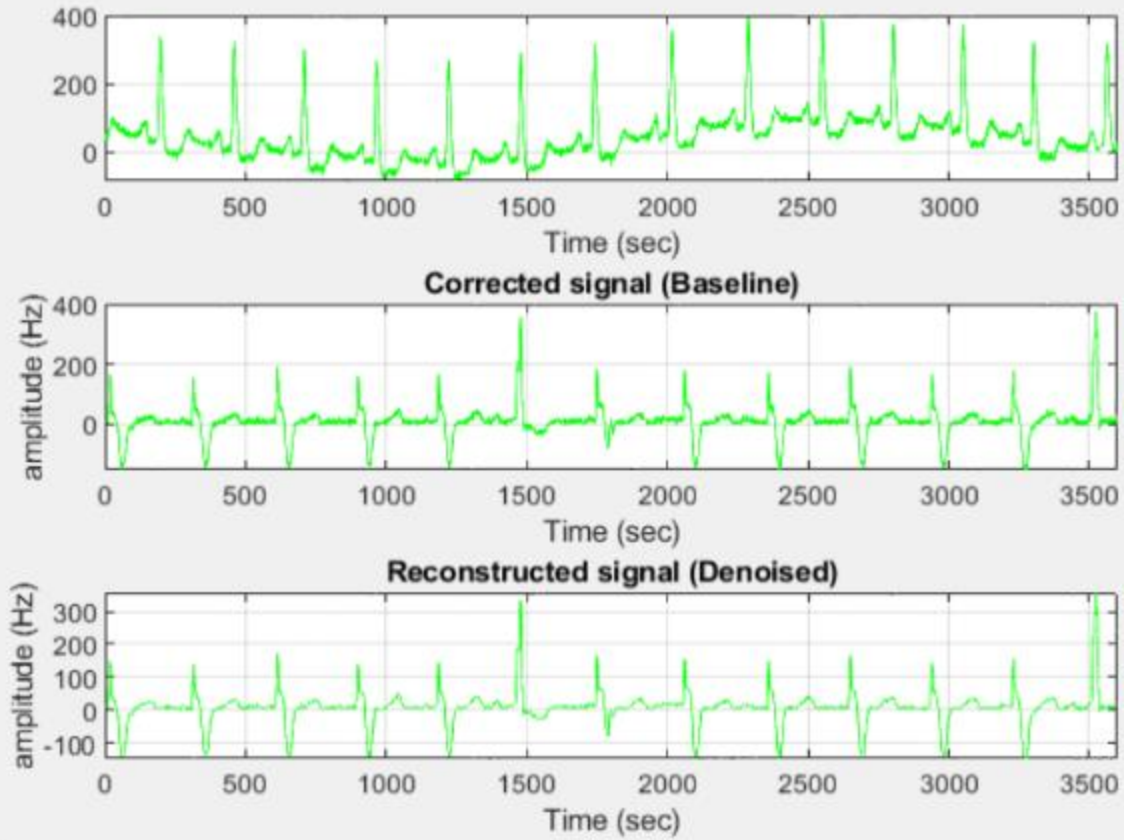
Dilation + Erosion = Closing operation

The operations use a structuring element pair
Bpair = {B1, B2}
where B1 is different from B2

Application of MMF Algorithm

$$f_{bc} = f_o - f_b = f_o - (f_o \circ B_o \bullet B_c)$$

$$\begin{aligned} f &= \tfrac{1}{2}\,(f_{bc} \bullet B_{pair} + f_{bc} \circ B_{pair}) = \\ &= \tfrac{1}{2}\,(f_{bc} \oplus B_1 \ominus B_2 + f_{bc} \ominus B_1 \oplus B_2) \end{aligned}$$



Performance evaluation of signal conditioning

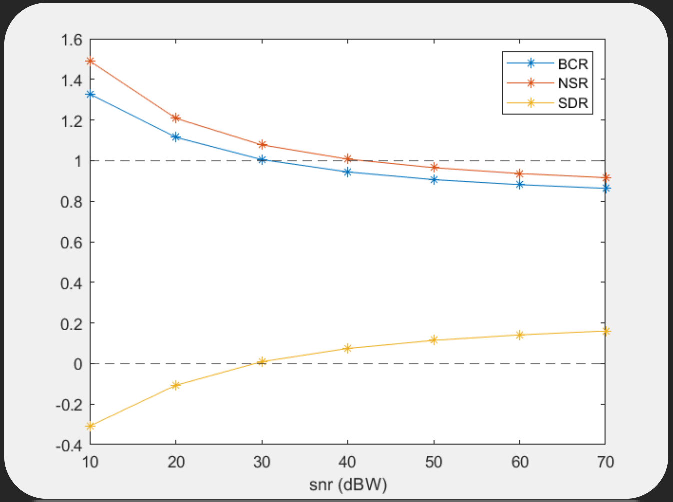
- Three parameters are used for algorithm evaluation:
  - the baseline-correction ratio (BCR),
  - the noise-suppression ratio (NSR),
  - and the signal-distortion ratio (SDR)

$$\mathrm{BCR} = \frac{\sum_{t=1}^{T} \|b(t)\|}{\sum_{t=1}^{T} \|b_o(t)\|},$$

$$\mathrm{NSR} = \frac{\sum_{t=1}^{T} \|n(t)\|}{\sum_{t=1}^{T} \|n_o(t)\|},$$

$$\mathrm{SDR} = \frac{\sum_{t=1}^{T} \|d_o(t)\| - \|\mathrm{d}(t)\|}{\sum_{t=1}^{T} \|\mathrm{d}(t)\|},$$

Comparison of BCR, NSR and SDR values with the variation of snr



Signal-to-noise ratio is a measure that compares the level of a desired signal to the level of background noise.

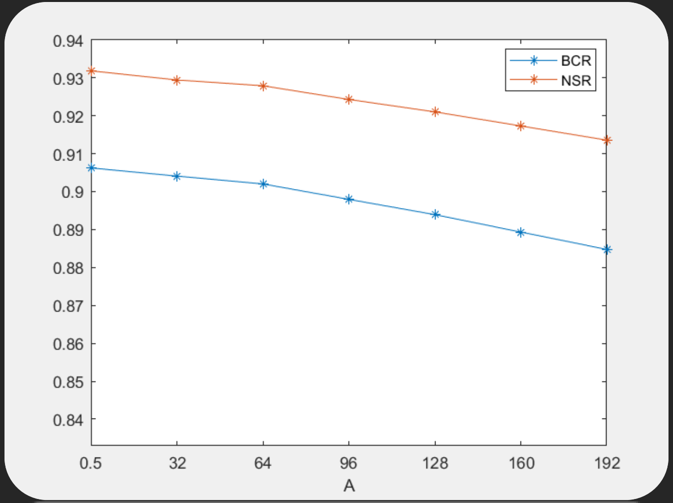
$SNR_{dB} = 10 \log_{10} (P_{signal} / P_{noise})$

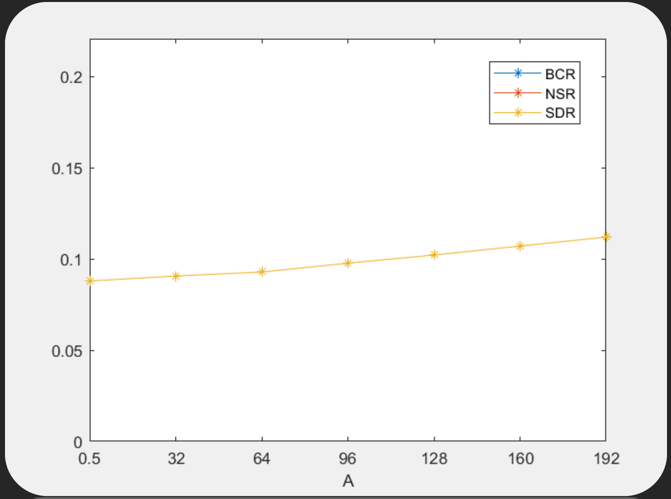
As SNR increases, the noise amplitude decreases.

$\sigma_{bcr} = 0{,}3869$; $\sigma_{nsr} = 0{,}2046$; $\sigma_{sdr} = 0{,}1682$;

The best instances obtained are between snr=30 and snr=40.

Comparison of BCR, NSR and SDR values with the variation of amplitude

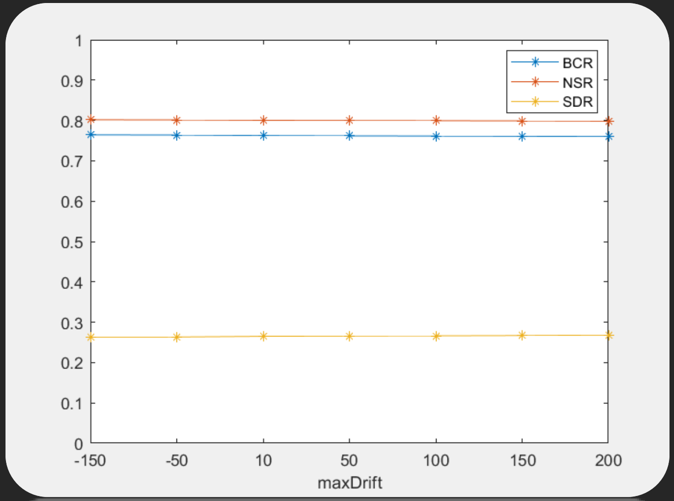


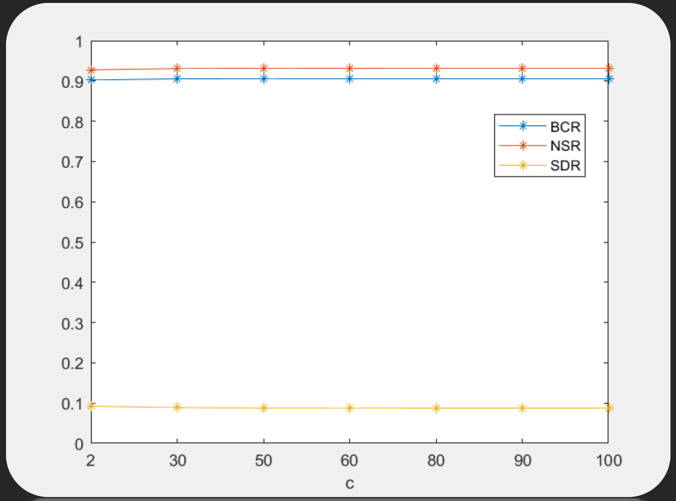


σ_{bcr} = 0,0080; σ_{nsr} = 0,0067; σ_{sdr} = 0,0089;

As A increases, the values of BCR, NSR and SDR slightly decrease.

Comparison of BCR, NSR and SDR values with the variation of drift and a constant c



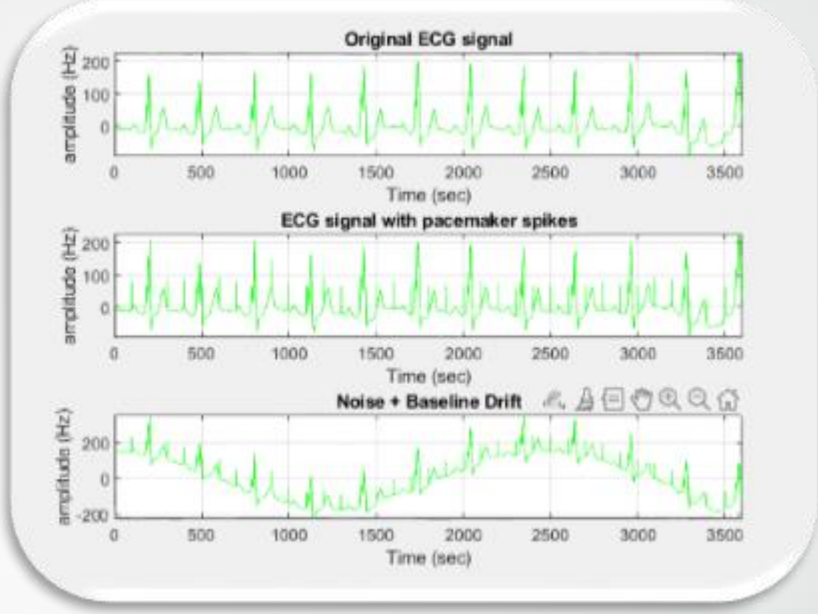


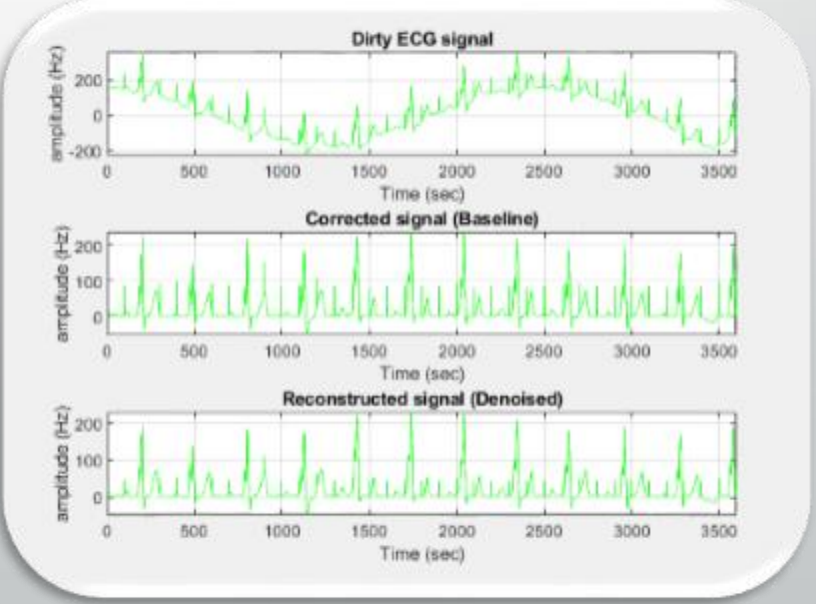
$\sigma_{bcr} = 0{,}0016$; $\sigma_{nsr} = 0{,}0013$; $\sigma_{sdr} = 0{,}0018$;

$\sigma_{bcr} = 0{,}0013$; $\sigma_{nsr} = 0{,}0015$; $\sigma_{sdr} = 0{,}0017$;

The BCR, NSR and SDR values don't change with the variation of maxDrift and c.

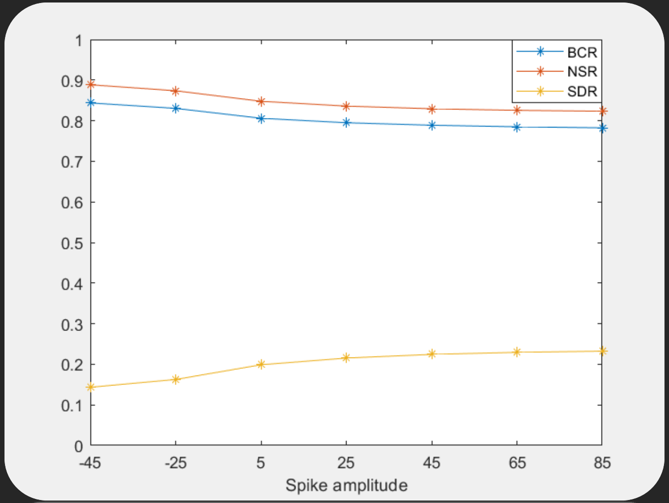
Application of MMF Algorithm on an ECG signal corrupted by pacemaker spikes





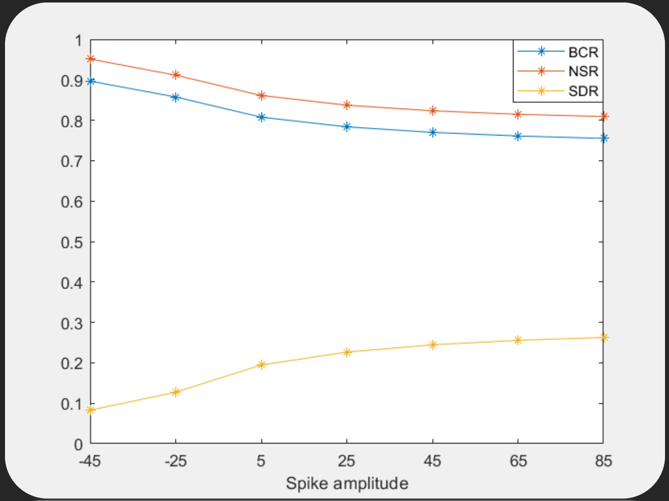
Comparison of BCR, NSR and SDR values with the variation of spike amplitude

(Without baseline drift)



σ_{bcr} = 0,0239; σ_{nsr} = 0,0255; σ_{sdr} = 0,0350;

(With baseline drift)



σ_{bcr} = 0,0537; σ_{nsr} = 0,0540; σ_{sdr} = 0,0692;

The MMF algorithm performed better considering negative spike amplitudes with the presence of baseline drift. As the spike amplitude increase, the BCR, NSR and SDR values decrease in both cases.

Conclusions

The MMF algorithm can retain the significant characteristic waves and intervals in the ECG signal

which is more important for subsequent processing, such as the ECG characteristic wave or interval detection, or arrhythmia recognition.