ECG signal conditioning by morphological filtering

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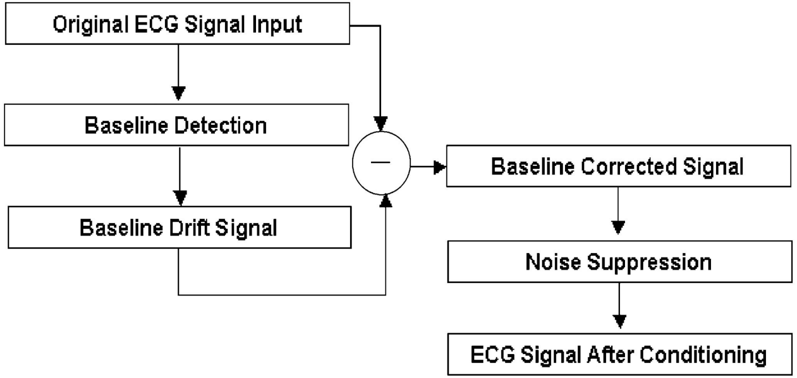
Introduction

- **Modified Morphological Filtering (MMF)** is a filtering technique used to clean and stabilize an ECG signal, with minimal signal distortion
- It performs signal conditioning, which is divided in two tasks: **baseline correction** and **noise suppression**
- Signal conditioning is typically the first step in the analysis of ECG signals, and it aims at producing an output that can facilitate subsequent processing
- The authors show that MMF performs well compared with existing methods, in terms of filtering characteristics, low signal distortion ratio, and low computational burden



MF vs MMF

- MMF uses **morphological operators**, which can extract the shape information of a signal by using structuring elements to operate on it
- In **Chu's MF algorithm**, baseline correction and noise suppression are performed as follows:

$$f_b = f_o \circ B_o \bullet B_c,$$

$$f = \tfrac{1}{2}[(f - f_b) \circ B \bullet B + (f - f_b) \bullet B \circ B]$$

- MMF inherits the same method for **baseline correction**, an opening operator followed by a closing operator
- For **noise suppression**, modified opening and closing operators are used, then the signal is processed through both operators concurrently, and the results are averaged

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

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

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

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

$$\text{opening}: f \circ B = f \ominus B \oplus B,$$

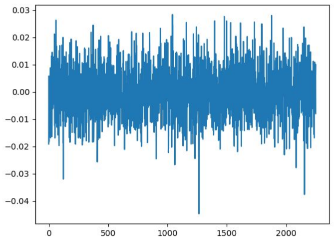
$$\text{closing}: f \bullet B = f \oplus B \ominus B,$$

Project pipeline

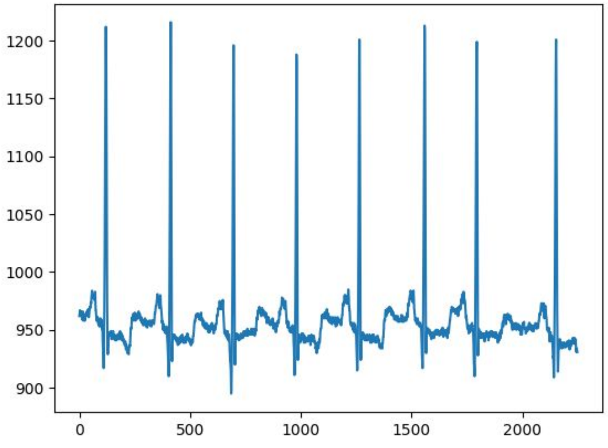
1. Get **ECG** signals from the **MIT-BIH arrhythmia database**
2. Add random **noise**
3. Add random **baseline drift**
4. Use a **R-peak detector** on the signals, and evaluate its performance w.r.t. the ground truth
5. Condition the signals by applying the **MMF algorithm**
6. Evaluate **changes in the performance** of the **R-peak detector**
7. Compute **metrics**, such as BCR, NSR and SDR

Adding noise

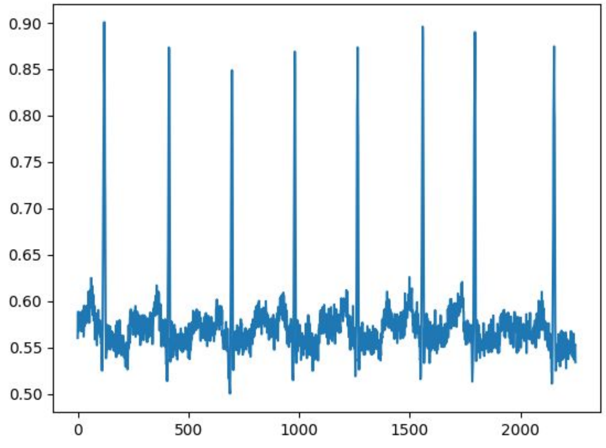
generated noise



original ECG

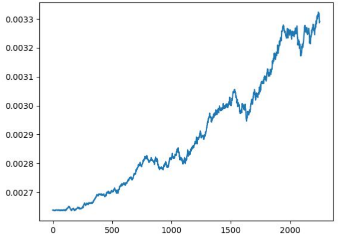


noisy ECG

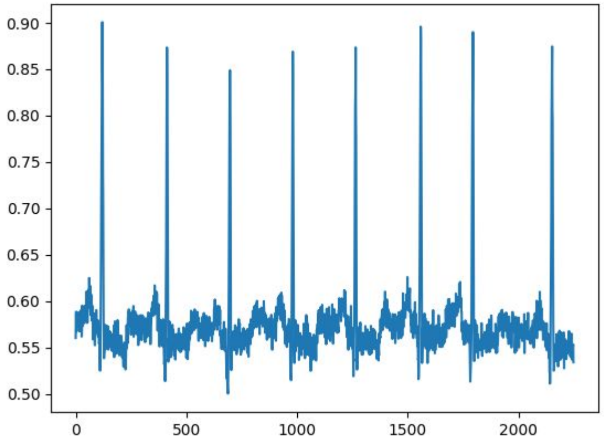


Adding baseline drift

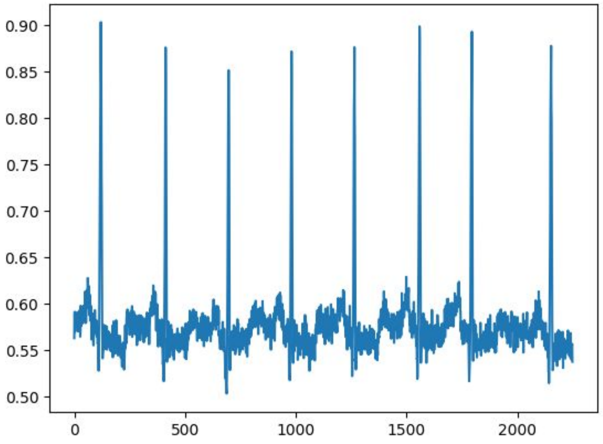
generated drift



noisy ECG

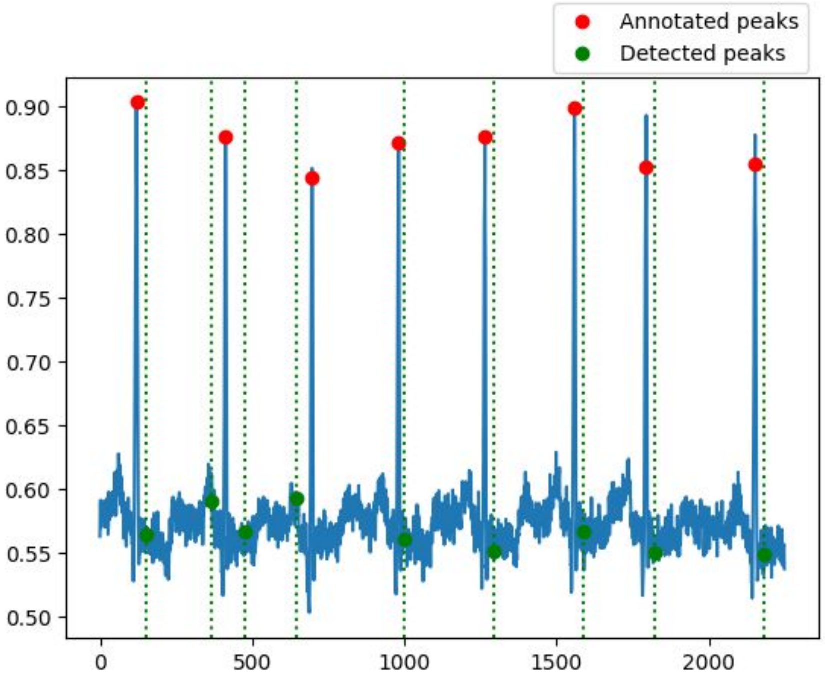


drifted ECG



R-peak detection

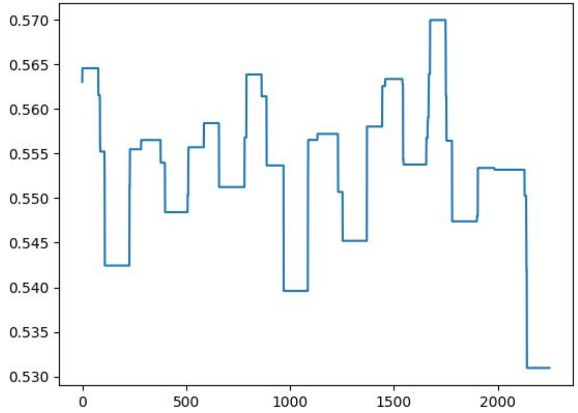
- Use a **peak detector** to find **R-peaks** in the ECG, after adding noise and baseline drift
- It's a **FIR matched filter** using templates of QRS complex
- It also uses the Pan and Tompkins thresholding method to distinguish between R-peaks and noise peaks
- The detected R-peaks are **compared with the annotated peaks** in the dataset, using a threshold to count a detection as correct
- Some **metrics** are computed: **accuracy**, **precision**, and **distance** (from detected to annotated peaks)



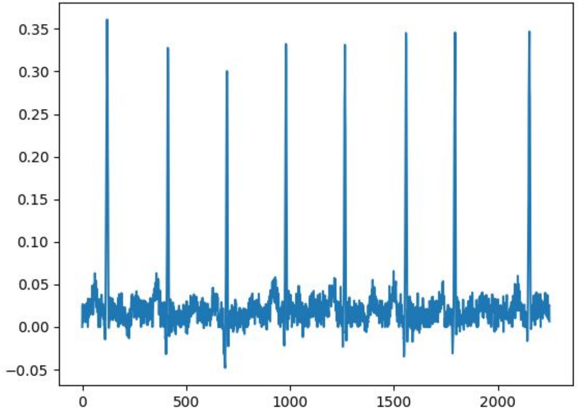
MMF (baseline correction)

Detected baseline drift: $f_b = f_o \circ B_o \bullet B_c$

- **Baseline correction** is performed by estimating the baseline drift, and then subtracting it from the signal
- Two structuring elements are used: one for the **opening** operation and one for the **closing** operation
- They’re both horizontal line segments of zero amplitude, with different lengths:
  - $\mathbf{B_o}$ has length **0.2 * $\mathbf{F_s}$**, where F_s is the sampling frequency
  - $\mathbf{B_c}$ has length of **1.5 times** the length of $\mathbf{B_o}$



baseline drift

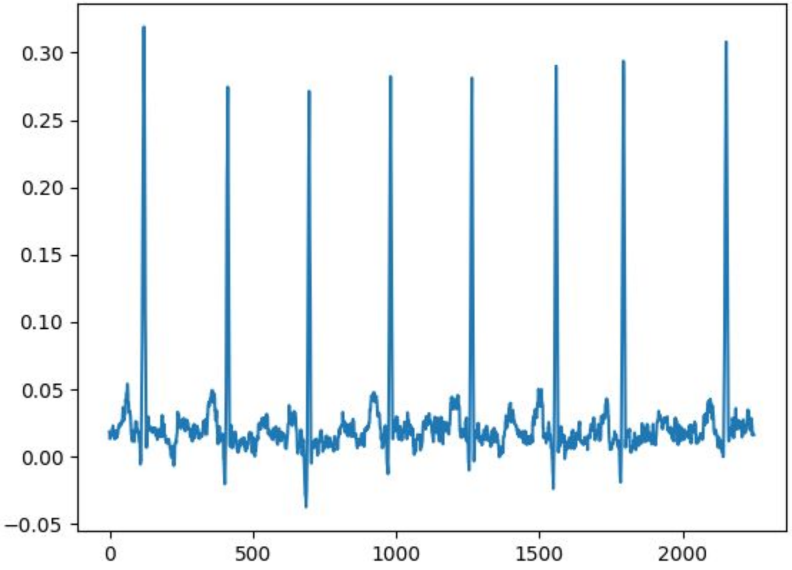


baseline corrected ECG

MMF (noise suppression)

- **Noise suppression** is performed by processing the data through an opening and closing operation concurrently, and then averaging the results
- A structuring element pair **B_{pair}** is used, it is defined as: $B_{\text{pair}} = \{B_1, B_2\}$
- **B_1** and **B_2** have the same length, but different shapes, in fact:
    - **B_1** is a triangular shape (to retain peaks and valleys of the characteristic wave)
    - **B_2** is a line segment (to remove noise)

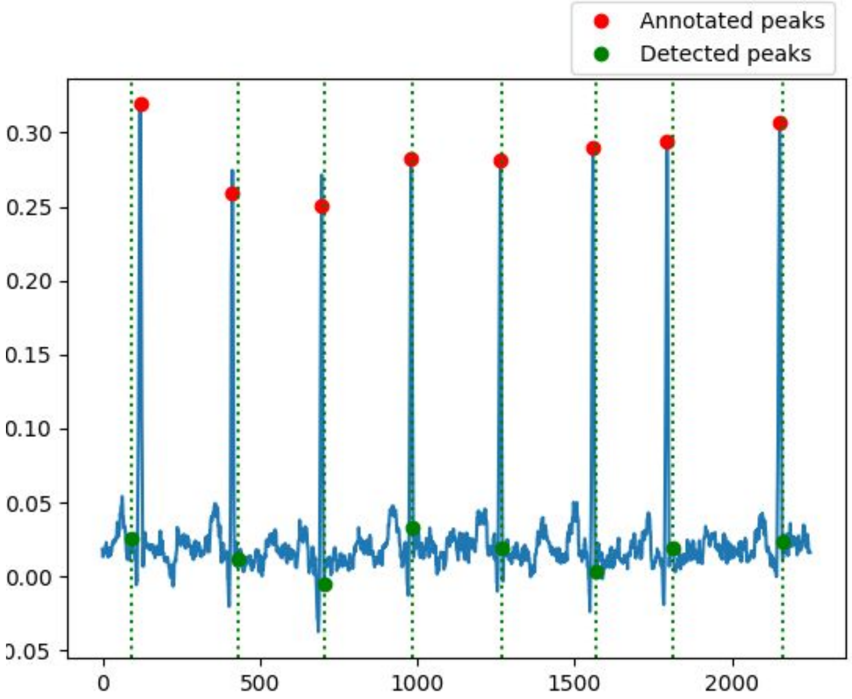
noise suppressed ECG



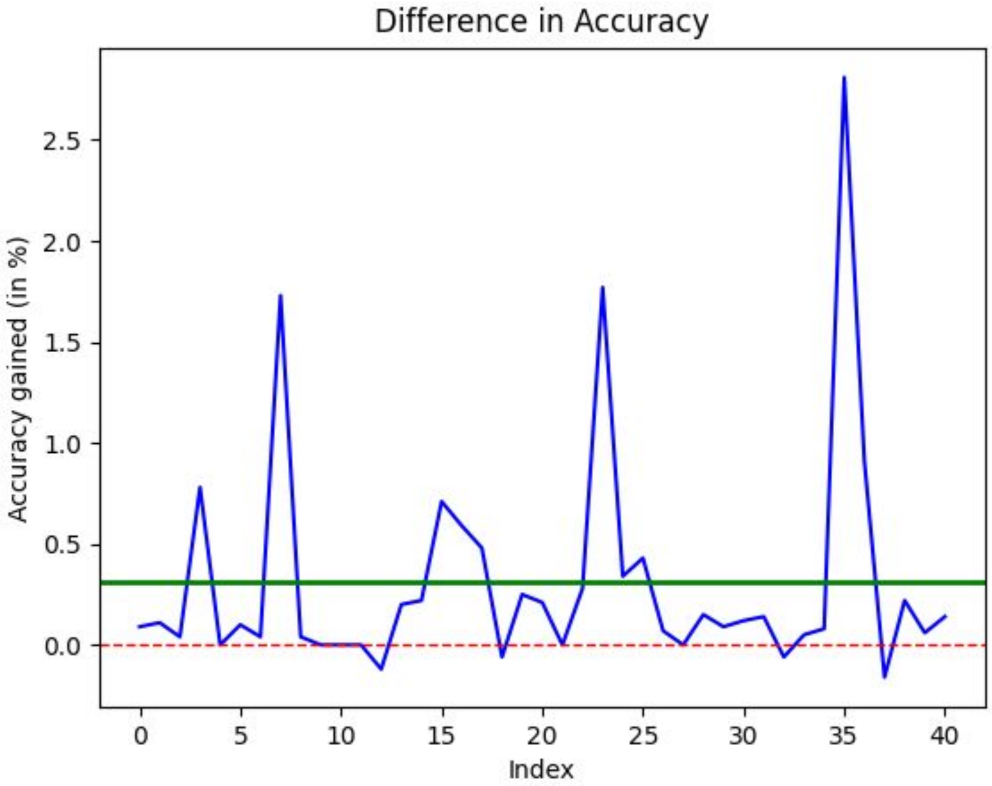
$$f = \frac{1}{2}(f_{\text{bc}} \bullet B_{\text{pair}} + f_{\text{bc}} \circ B_{\text{pair}})$$
$$= \frac{1}{2}(f_{\text{bc}} \oplus B_1 \ominus B_2 + f_{\text{bc}} \ominus B_1 \oplus B_2)$$

R-peak detection (after MMF)

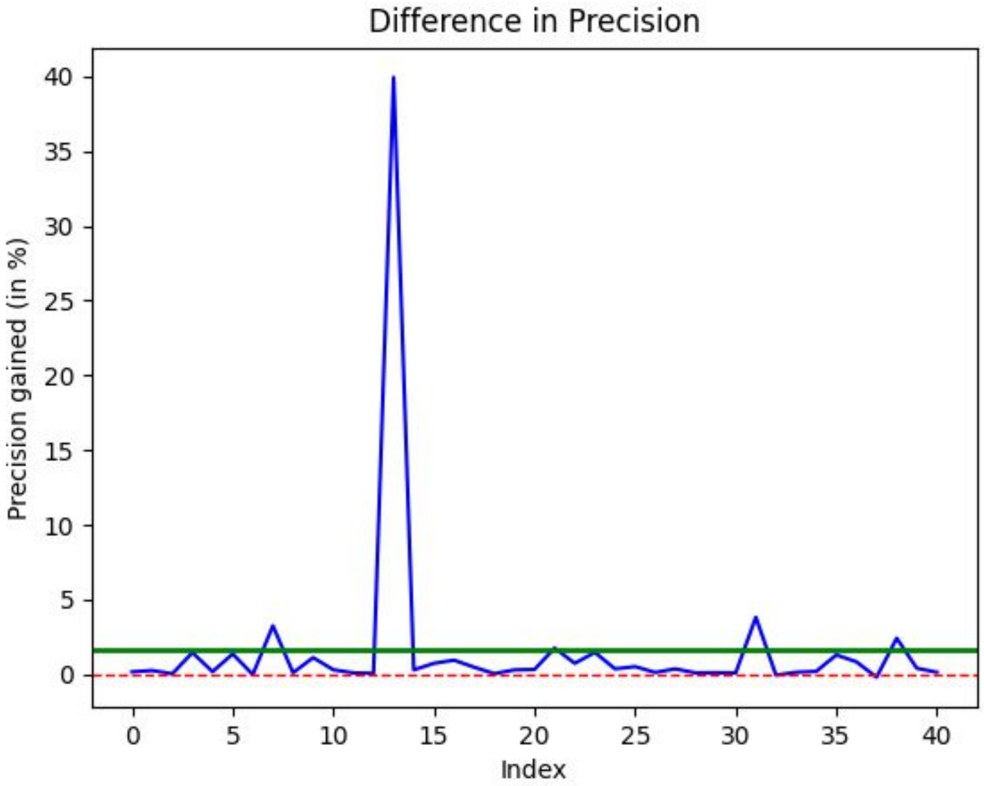
- Use the **peak detector** to find **R-peaks** in the ECG, after conditioning the signal with the MMF algorithm
- Again, **metrics** are computed and compared to the previous results to show the benefits of conditioning



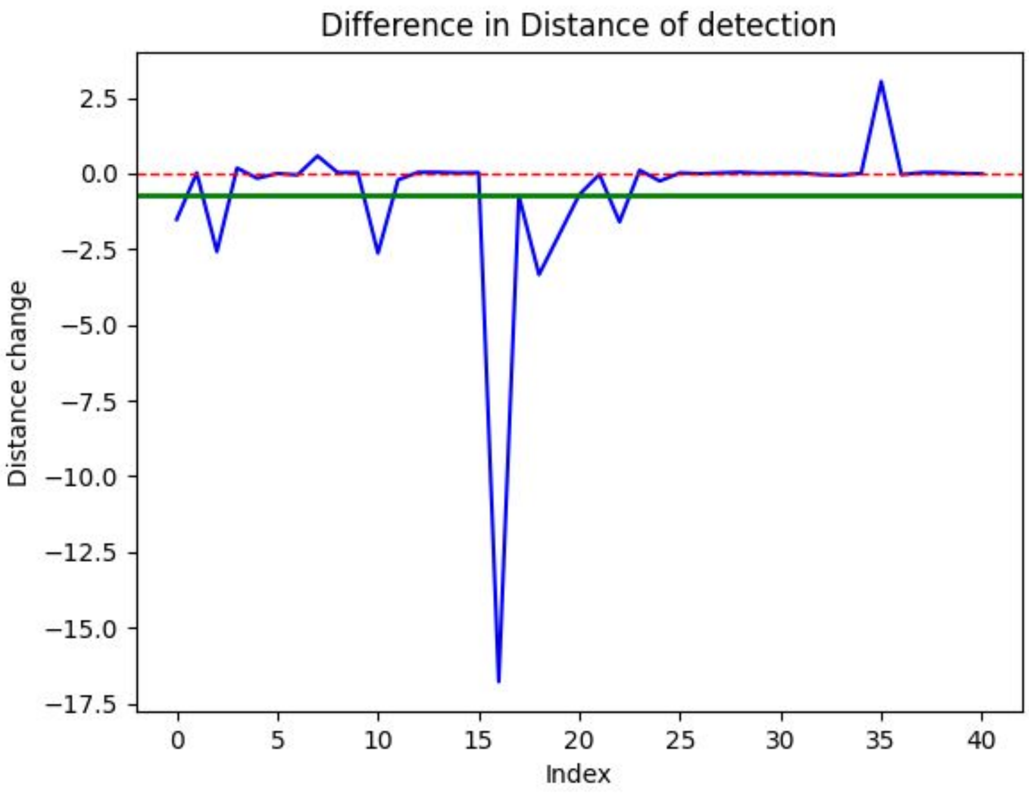
R-peak detection improvements after MMF



R-peak detection improvements after MMF

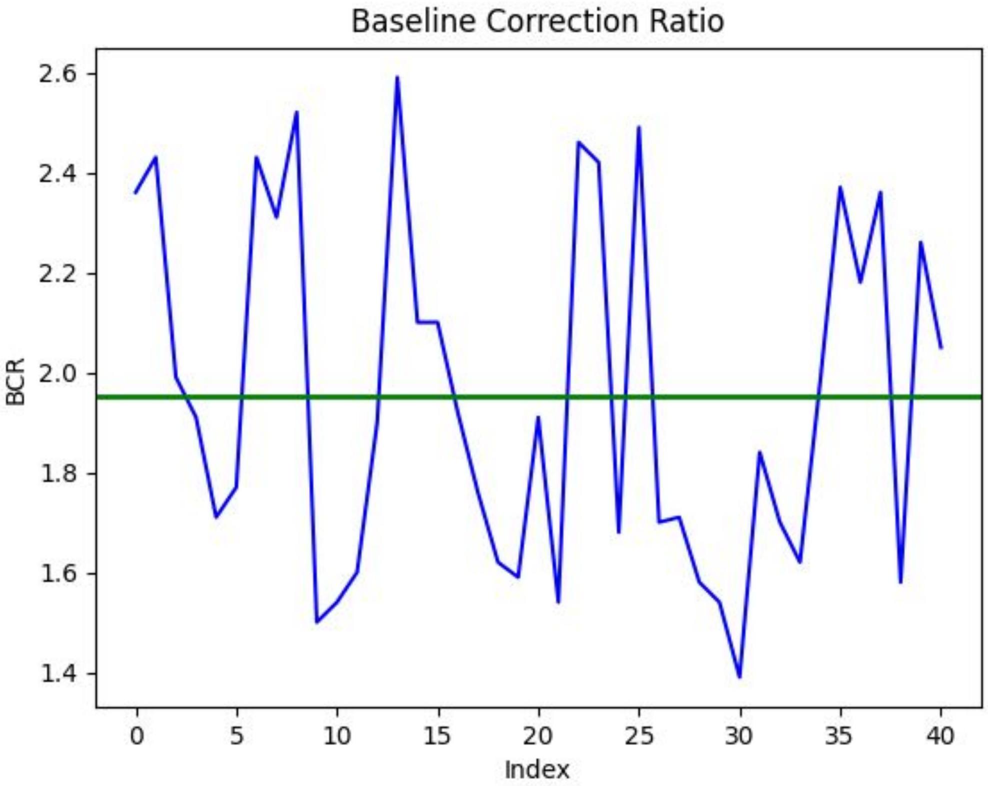


R-peak detection improvements after MMF



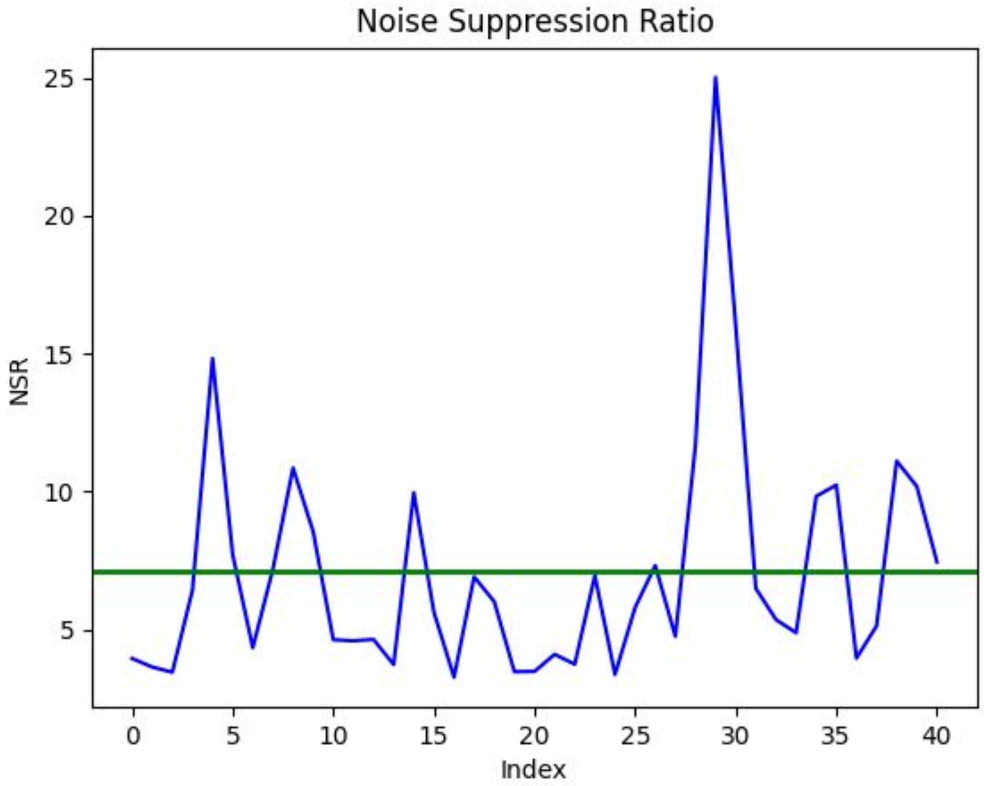
Baseline Correction Ratio

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



Noise Suppression Ratio

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



Signal Distortion Ratio

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