INTRODUCTION

- **Modified Morphological Filtering** (MMF) is a filtering technique used to «clean up» the signal with minimal signal distortion

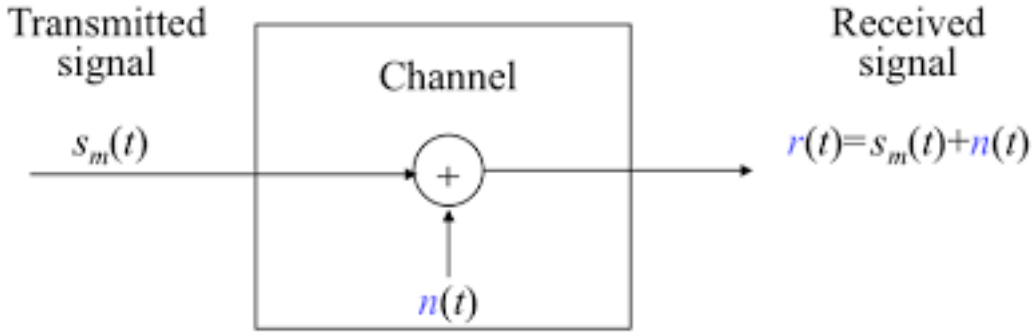
- It allows to obtain reliable results and therefore facilitate the interpretation of the ECG signal

PROJECTUAL STEPS

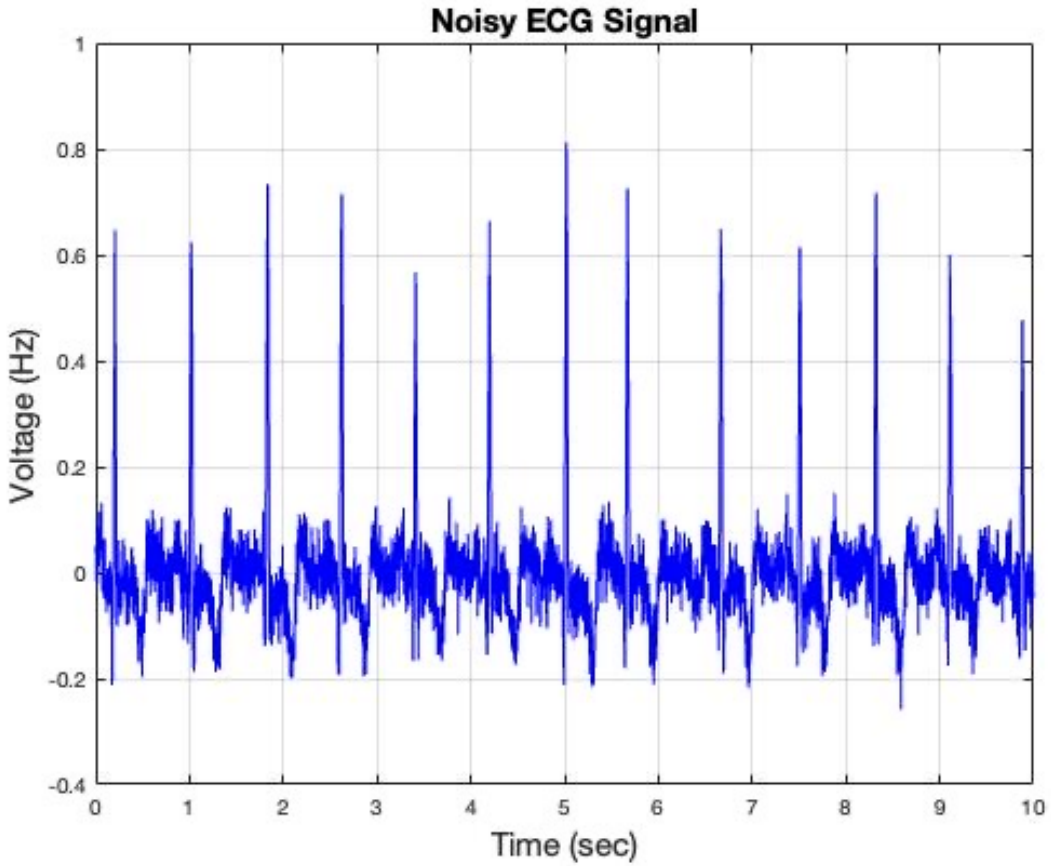
1. Work on a data set of ECG signals
2. Add variable noise to the signals
3. Add variable baseline drift to the signals
4. Conditioning the signals by MMF algorithm and MF anlgorithm
5. Evaluate the performance of the algorithms
6. Evaluate the two algorithms by varying the length of the structuring element and the noise applied to the signals

ADDING NOISE

- In order to add noise to the ECG signal, the Additive White Gaussian Noise (AWGN) was chosen for its simplicity and effectiveness in application
- The SNR (Signal to Noise Ratio) is computed randomly to distribute different noises within the data set



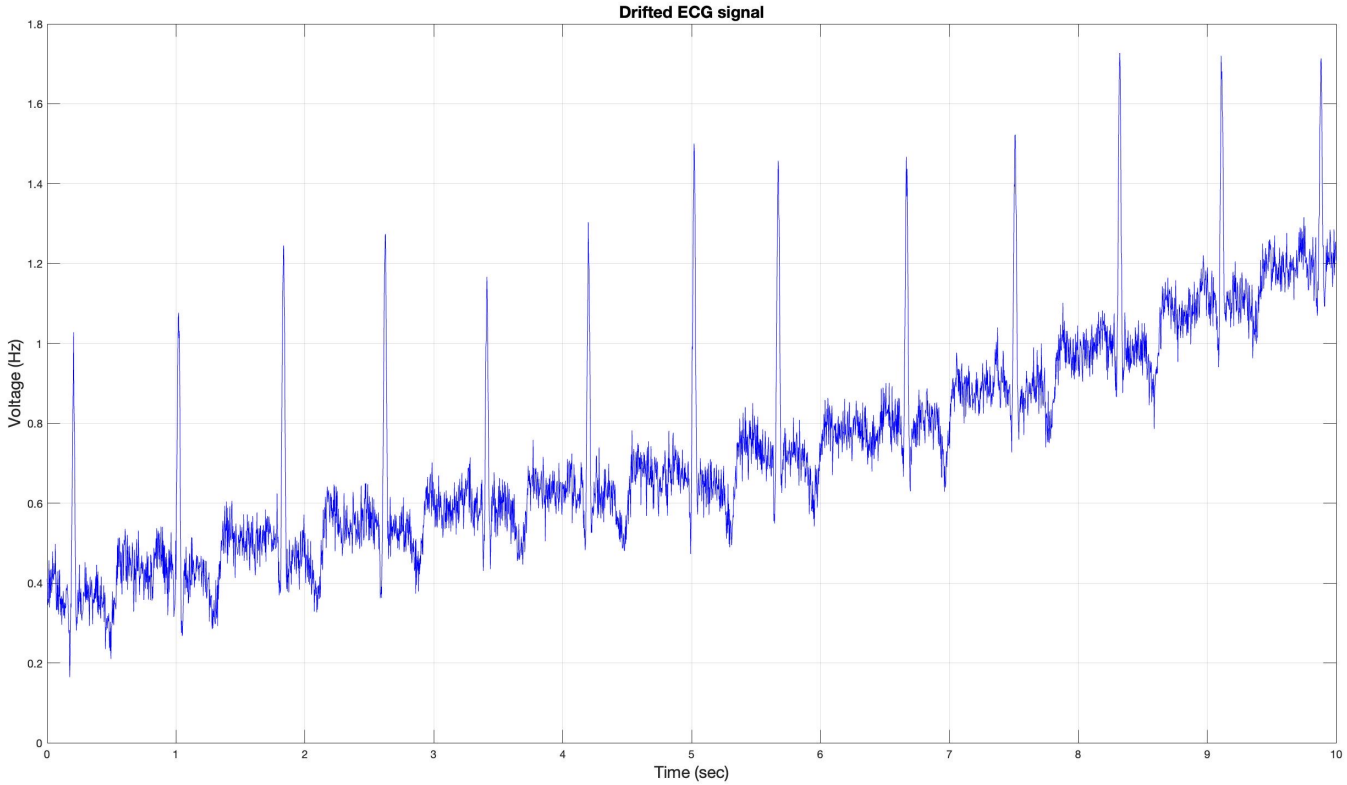
NOISE APPLIED TO A SIGNAL



ADDING BASELINE DRIFT

- Baseline Drift is simulated by adding a slanted line to a sinusoidal signal
- The function called ***GenDrift***, takes care of randomly generating a drift to be applied to all signals in the data set

BASELINE DRIFT APPLIED TO A NOISY SIGNAL



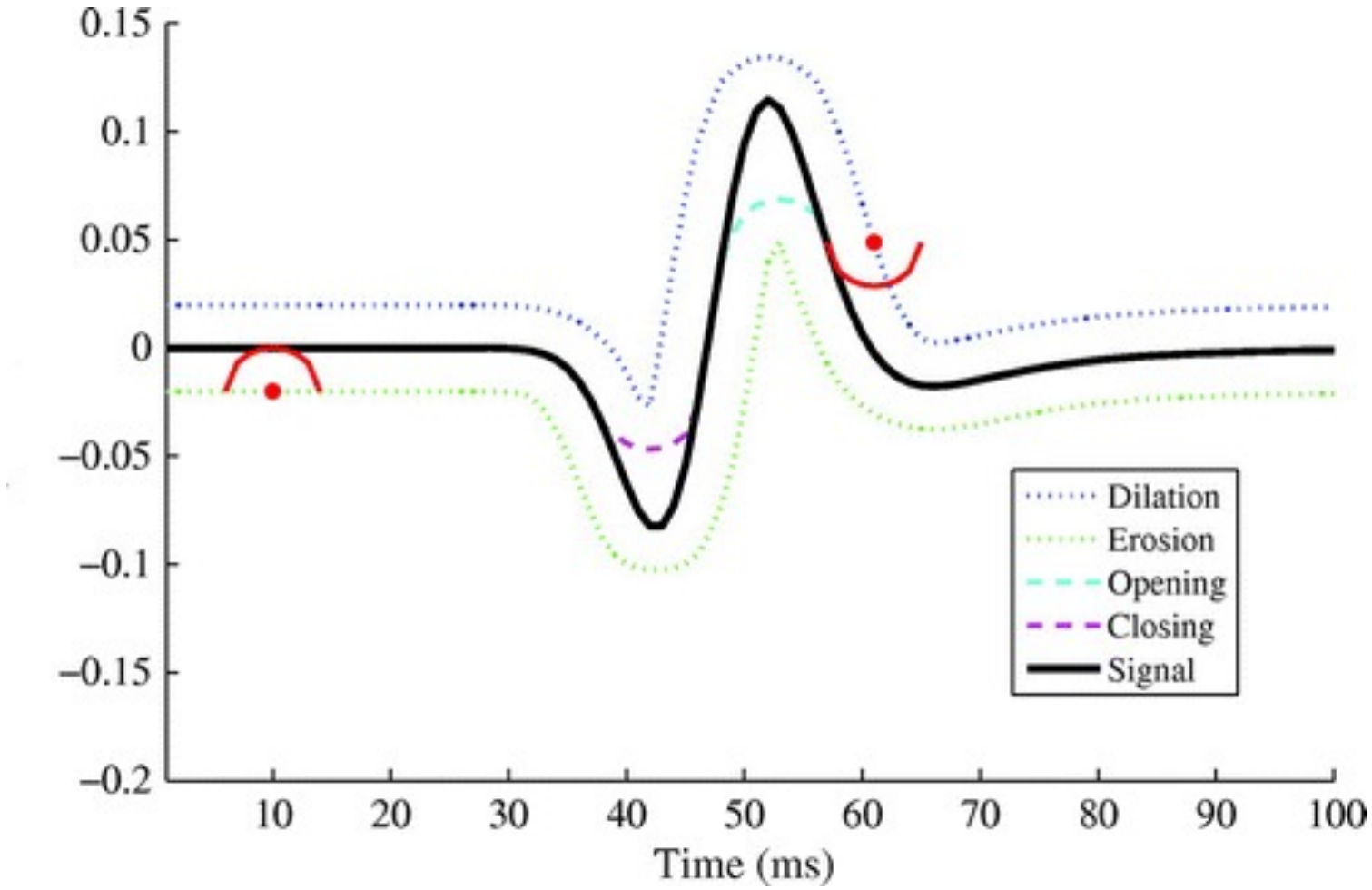
MATHEMATICAL MORPHOLOGY OPERATORS

Basic morphological operators:

- **Erosion** ($\ominus$): is a «shrinking» operation. Basically consists in subtracting the structuring element from the input signal, and finding the minimum value of the differences.
- **Dilatation** ($\oplus$): is an «expansion» operation. Basically consists in adding the structuring element to the input signal, and finding the maximum value of the sums.

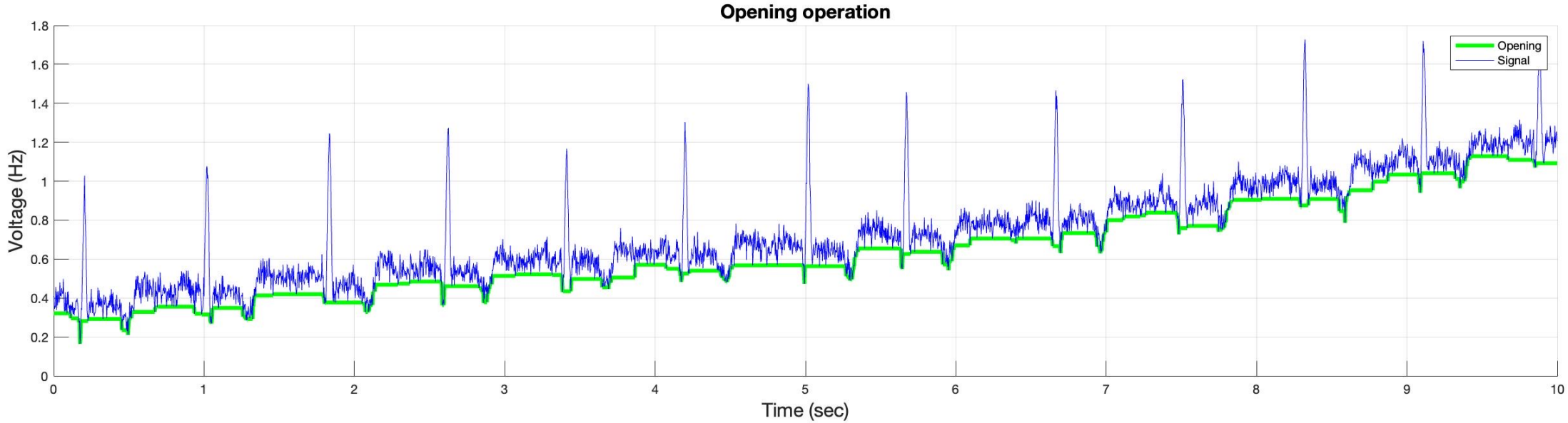
From the first one are derived the following operation:

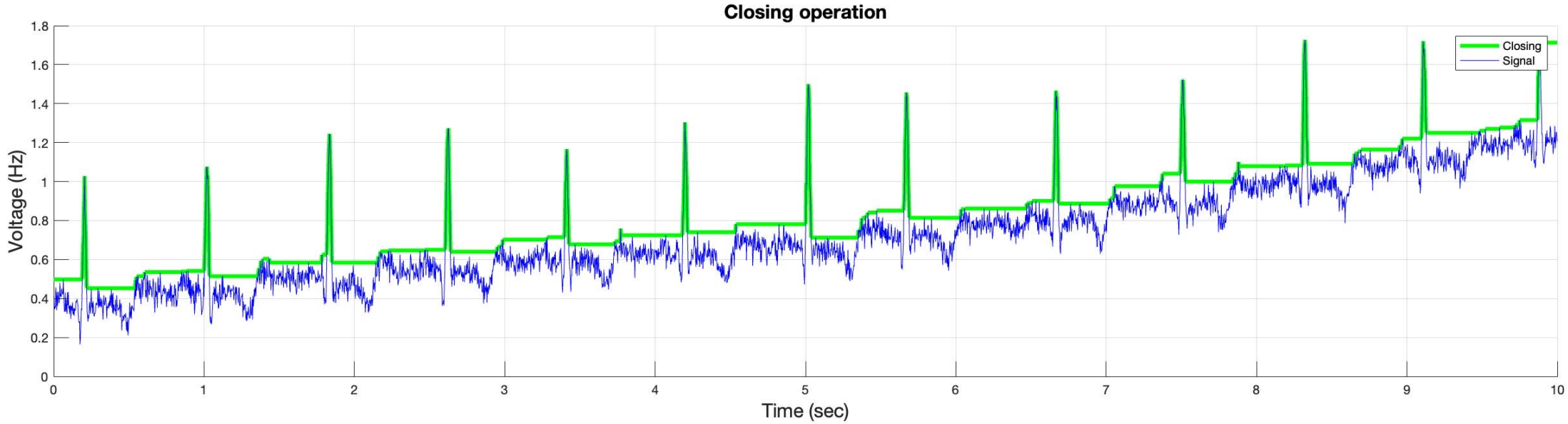
- **Opening** ($\circ$): used to suppress peaks.
- **Closing** ($\bullet$): used to suppress pits.

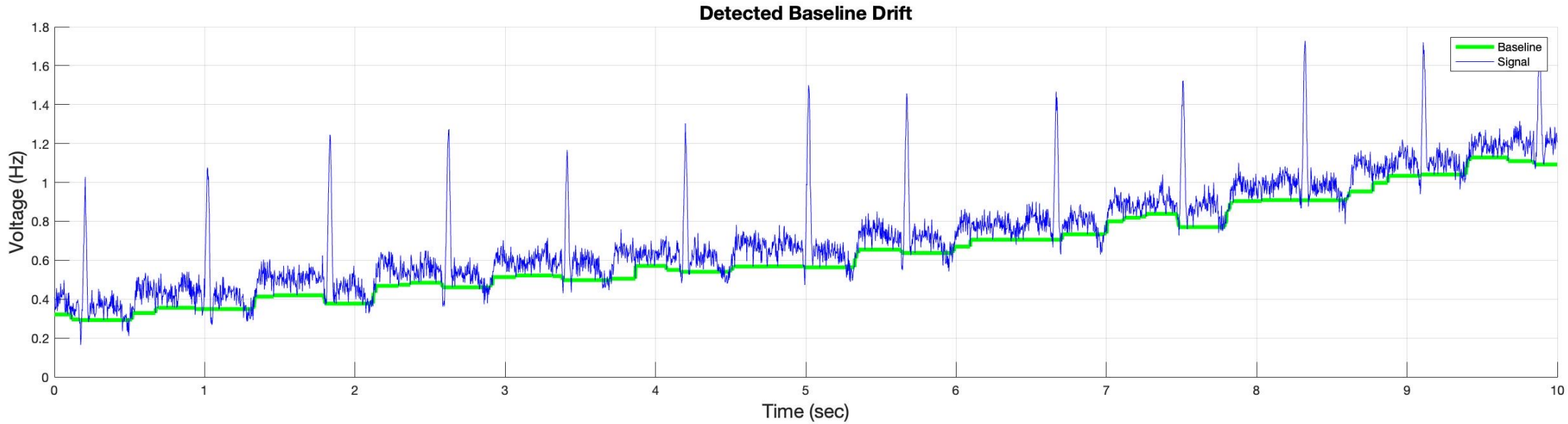

0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
10
20
30
40
50
60
70
80
90
100
Time (ms)
Dilation
Erosion
Opening
Closing
Signal

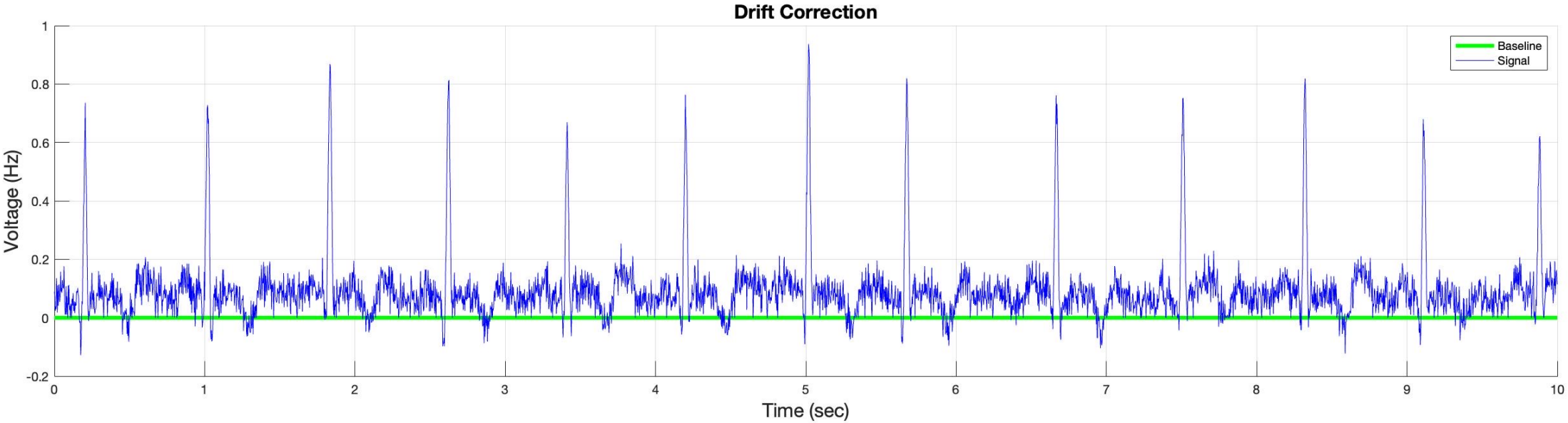
BASELINE DRIFT CORRECTION

- Baseline drift correction is performed by estimating the drift and subtracting it from the signal
- Two structuring elements are used: one for removing peaks (B_o) and the other (B_c) for removing pits left after the previous passage
- B_o and B_c are built as two horizontal line segments of zero amplitude with the lengths that depends on the duration of the characteristic wave and the sample frequency
- Detected badeline drift: $f_b = f_o \circ B_o \bullet B_c$


Opening operation
Opening
Signal
Voltage (Hz)
Time (sec)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7
8
9
10


Closing operation
Closing
Signal
Voltage (Hz)
Time (sec)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7
8
9
10

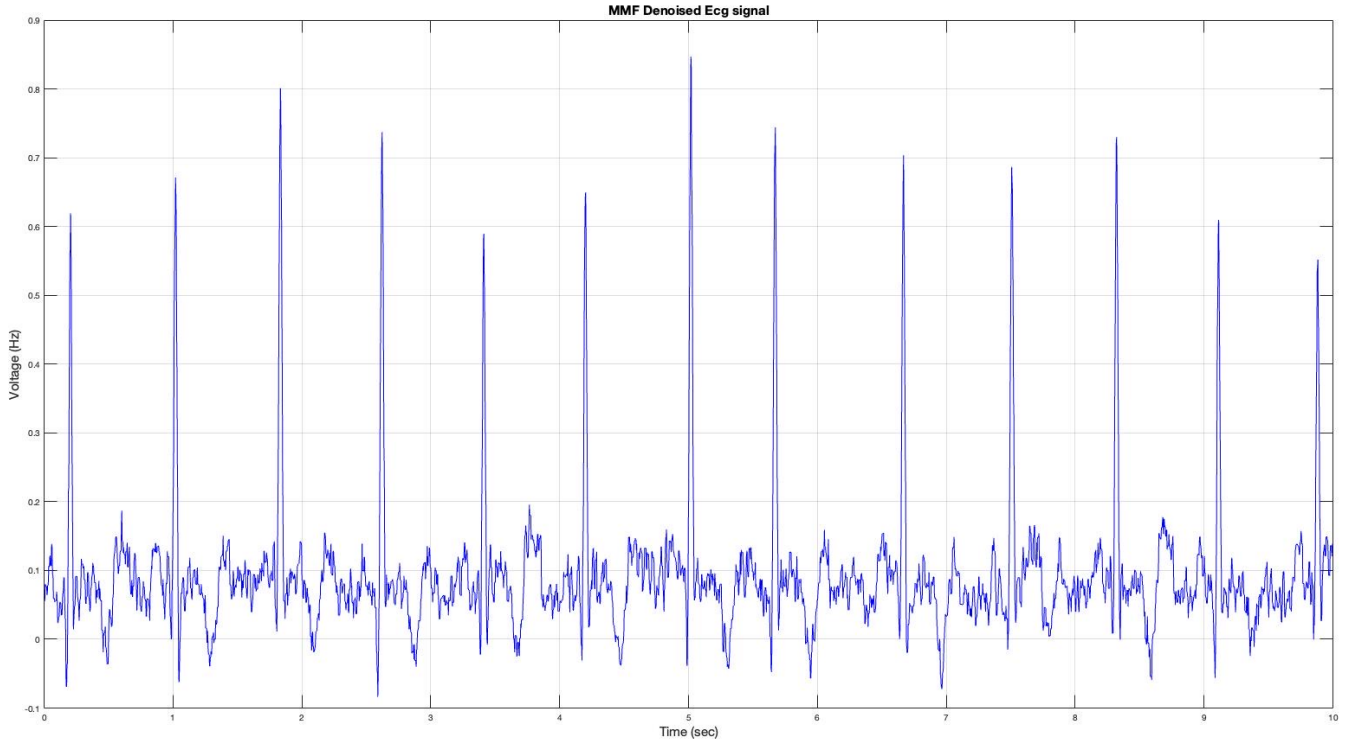

Detected Baseline Drift
Baseline
Signal
Voltage (Hz)
Time (sec)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7
8
9
10


Drift Correction
Baseline
Signal
Voltage (Hz)
Time (sec)
-0.2
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7
8
9
10

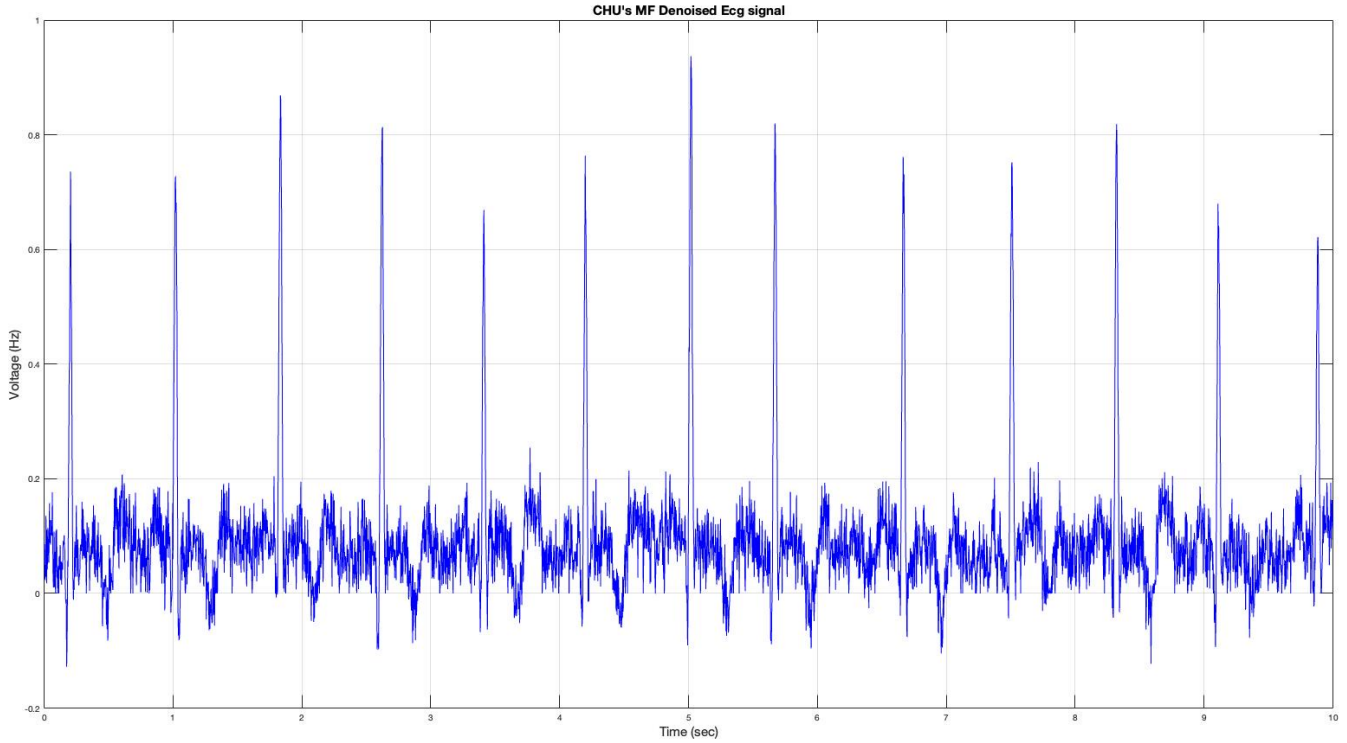
MMF: NOISE SUPPRESSION

- Noise suppression is performed by processing the signal through a sequence of opening and closing operation concurrently, and then the results are averaged.
- The operations are carried out through a structuring element called $\boldsymbol{B_{pair}}$, which is composed of two elements, $\boldsymbol{B_1}$ and $\boldsymbol{B_2}$, having the same length to minimize signal distortion
- $\boldsymbol{B_1}$ has a triangular form used to retain the peaks and valley of the characteristic waves
- $\boldsymbol{B_2}$ is a line segment used to removing noise
- $f = \frac{1}{2}\left(f_{bc} \bullet B_{pair} + f_{bc} \circ B_{pair}\right) = \frac{1}{2}(f_{bc} \oplus B_1 \ominus B_2 + f_{bc} \ominus B_1 \oplus B_2)$

MMF DENOISING

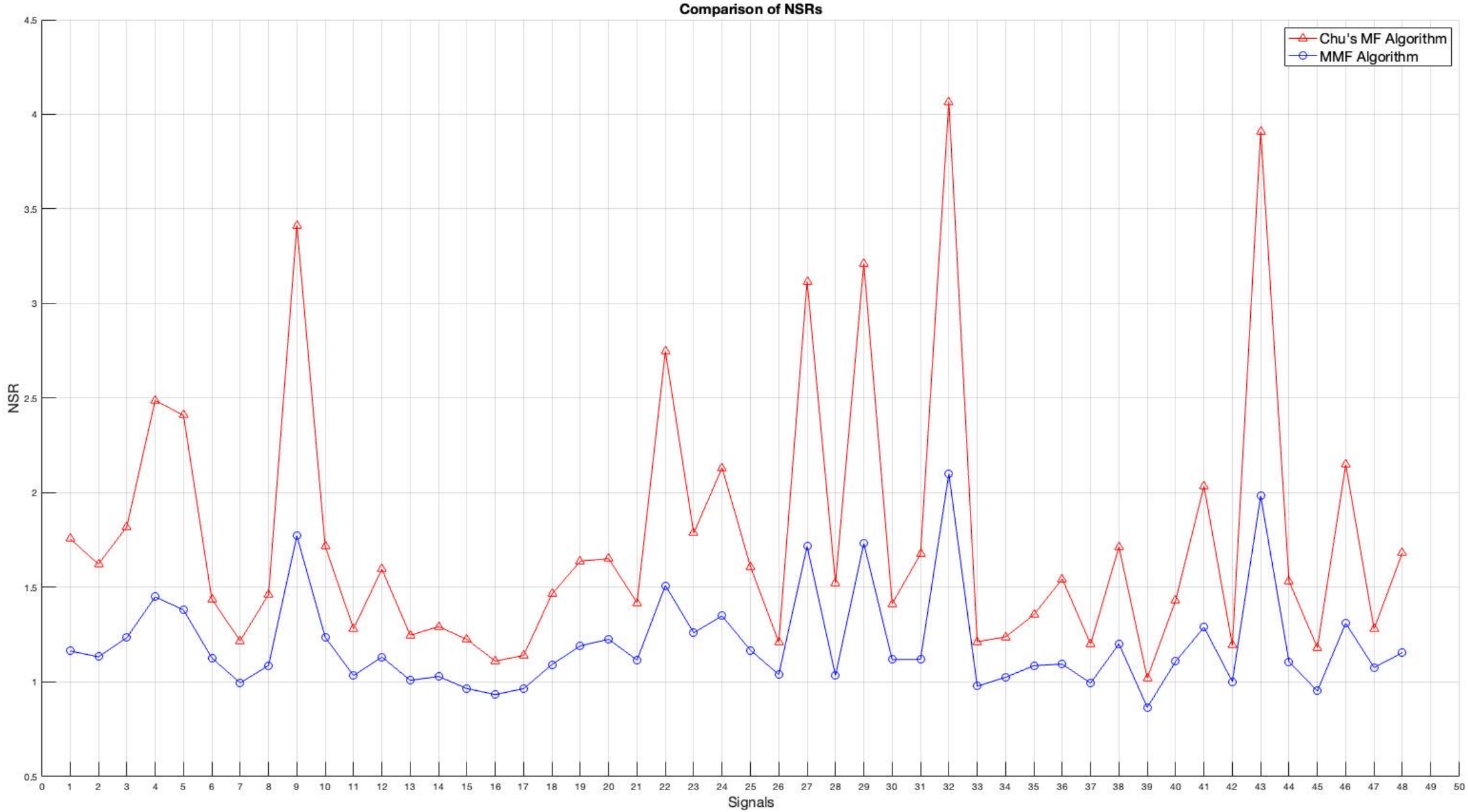


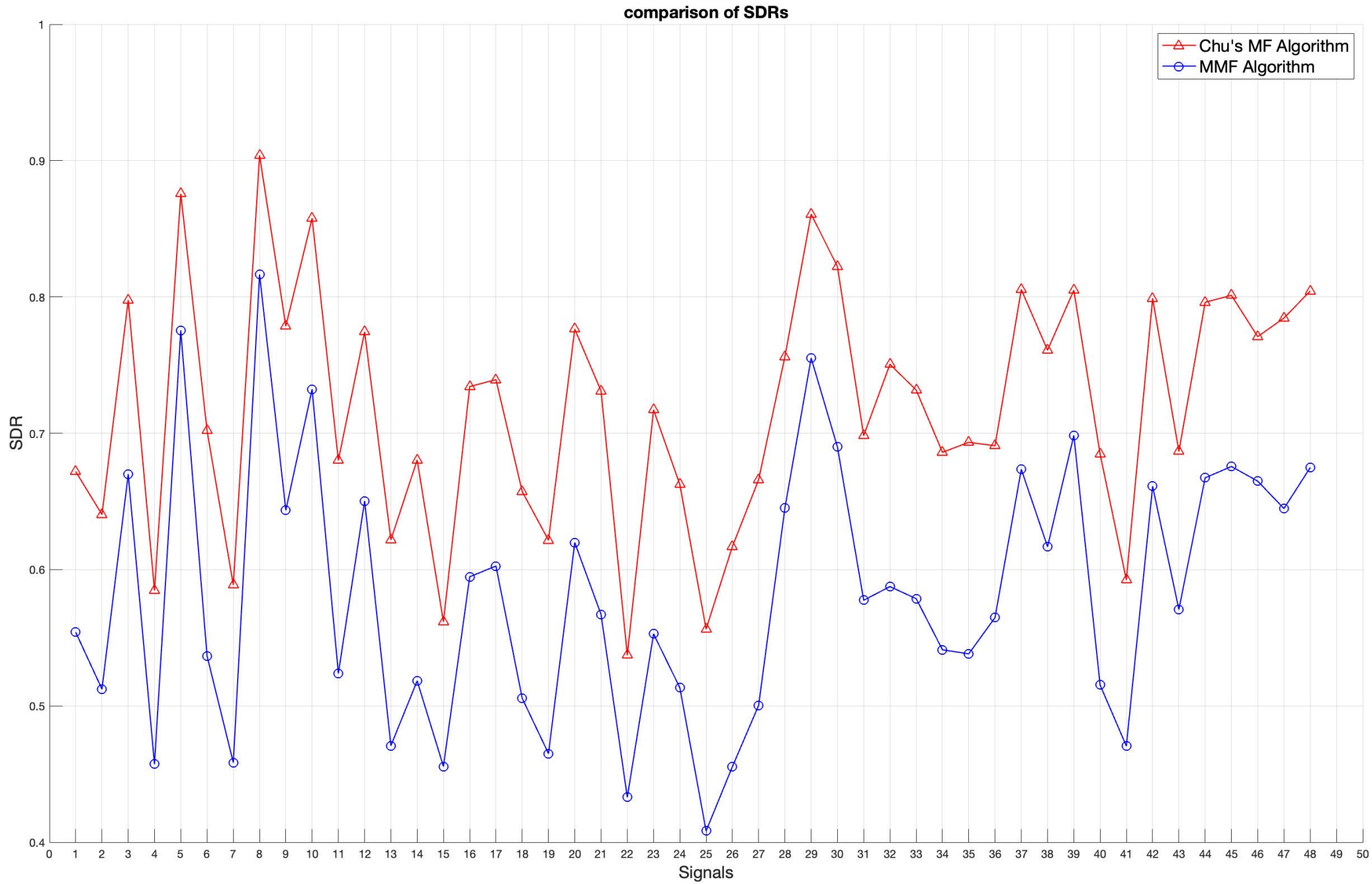
MF DENOISING



EVALUATION

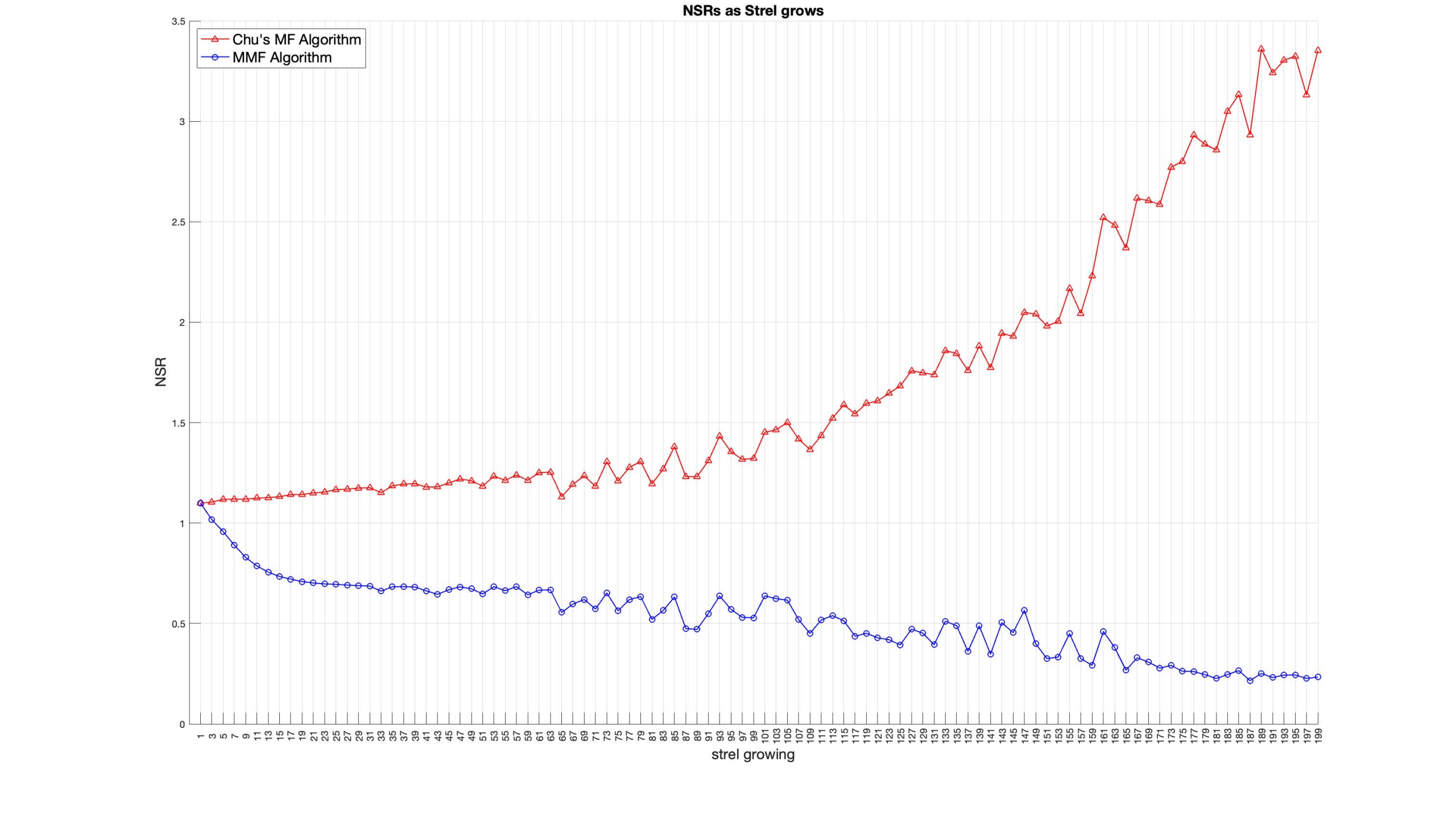
- The performance of the algorithms are evaluated based on the level of **noise reduction** achieved and on the **distortion** caused in the signal
- Two main parameters are judged: the Noise-Suppression ratio (**NSR**) and the Signal-Distortion ratio (**SDR**)
- To give reliable results it is important to **minimize the distortion** of the ECG signal caused by signal conditioning
- The MMF algorithm retain the significant singular points, therefore is preferred

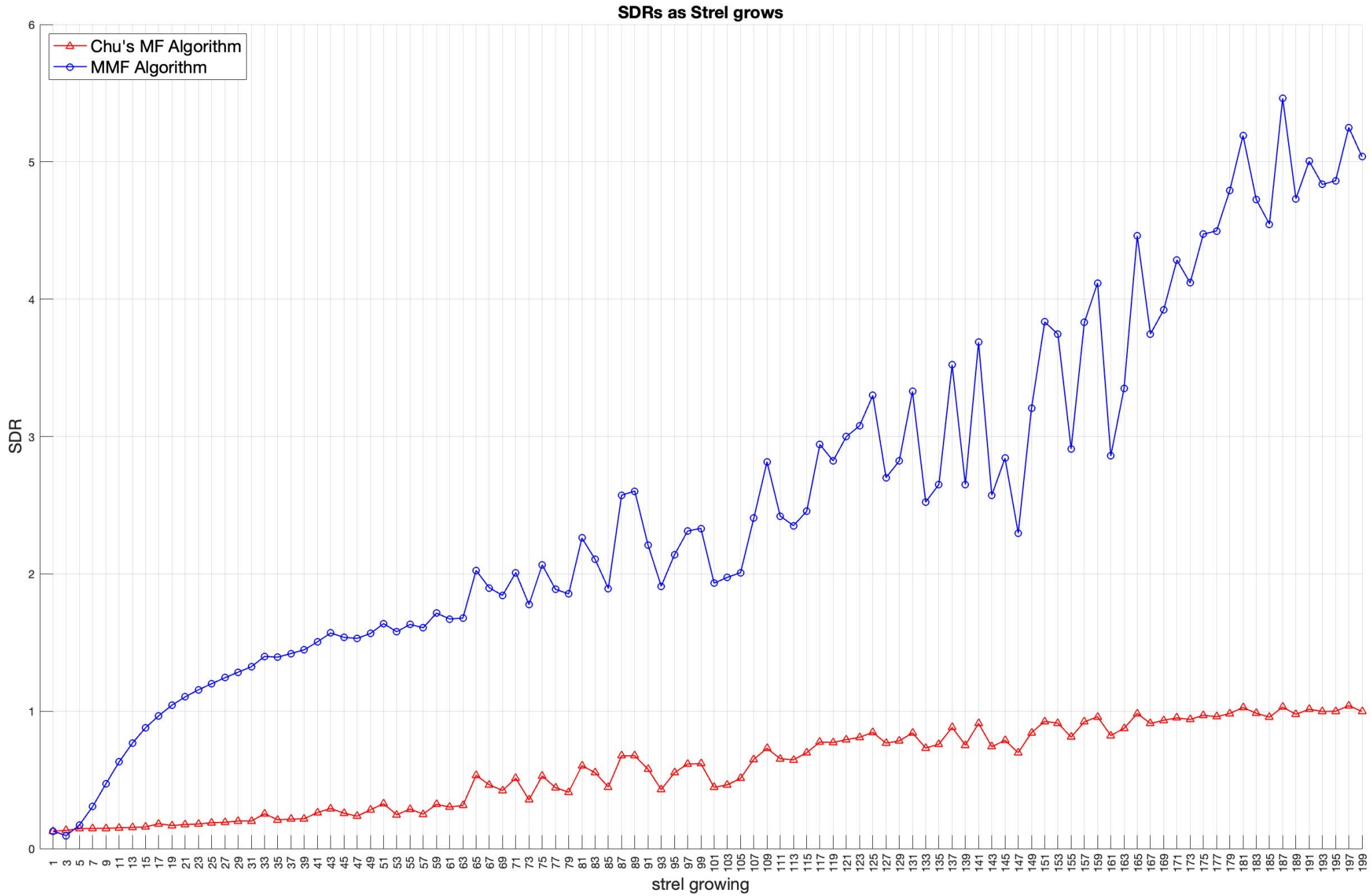

Comparison of NSRs
Chu's MF Algorithm
MMF Algorithm
NSR
Signals
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50


comparison of SDRs
Chu's MF Algorithm
MMF Algorithm
SDR
Signals
1
0.9
0.8
0.7
0.6
0.5
0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

FINAL EVALUATION

- Final evaluation performed on the data set as the length of the structuring element grows and the SNR (Signal to Noise Ratio) increases
- For *N* structuring element (generated through '*GenStrel*'), run the MMF and MF algorithm on the entire dataset
- For each *mmf-th* and *mf-th*, compute the NSR and the SDR, obtaining *N* sets one for each structuring element applied, representing the evaluation signal by signal
- For each N-*th* set calculate the mean, thus obtaining the mean values of the NSR and SDR calculated for the MMF and MF algorithm


NSRs as Strel grows
Chu's MF Algorithm
MMF Algorithm
NSR
strel growing
0
0.5
1
1.5
2
2.5
3
3.5


SDRs as Strel grows
Chu's MF Algorithm
MMF Algorithm
SDR
strel growing
0
1
2
3
4
5
6