Homework - Topic 2:

Decomposition and Reconstruction of Biosignals

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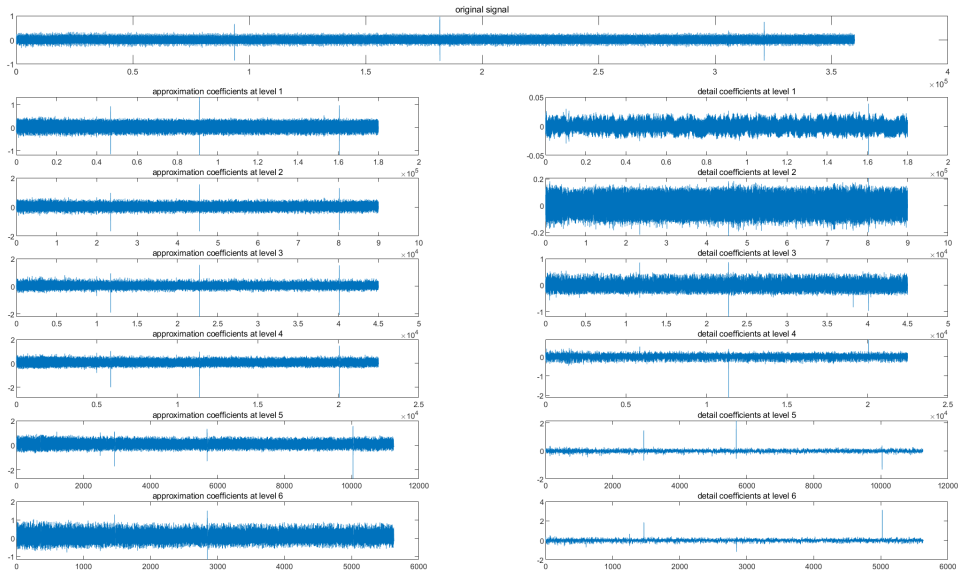
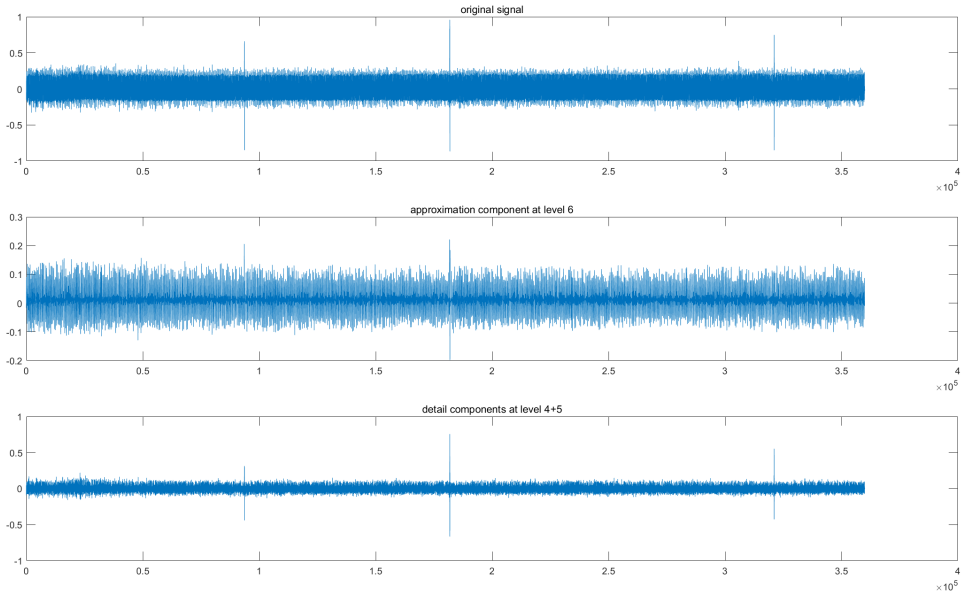
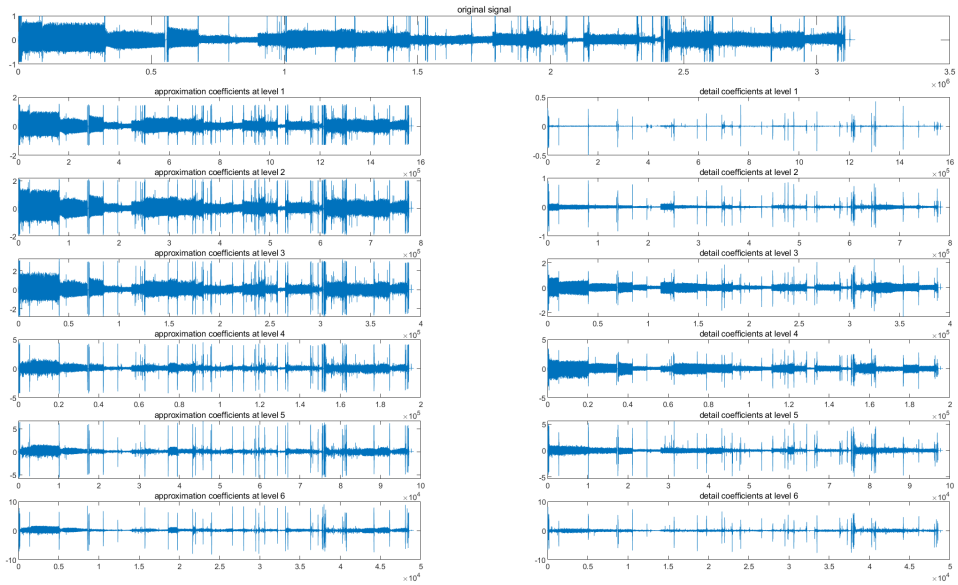
1. Try MATLAB sample code

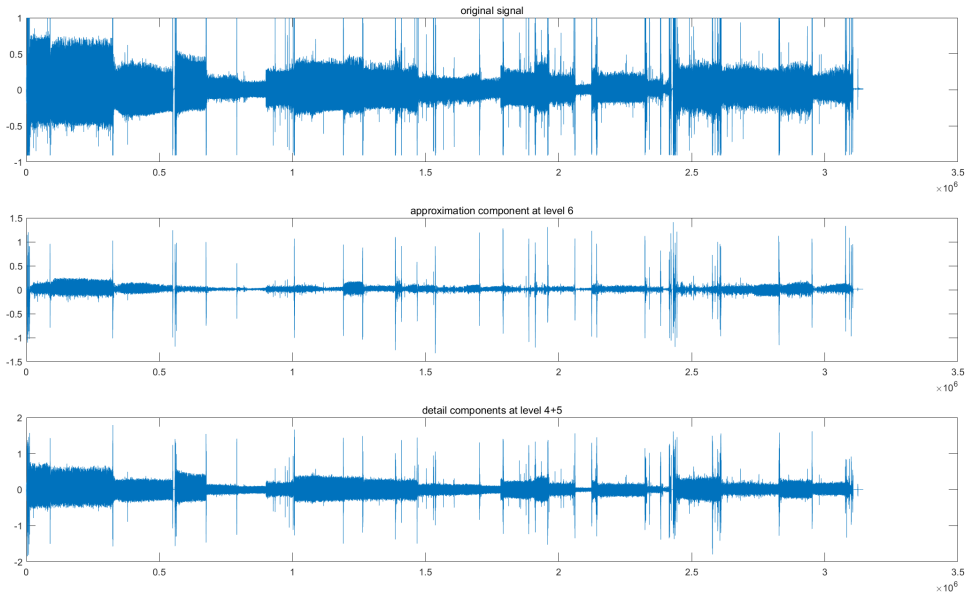
- **wavelet1hr.m**
  - **wavelet1hr.m** with **data1hr.txt**





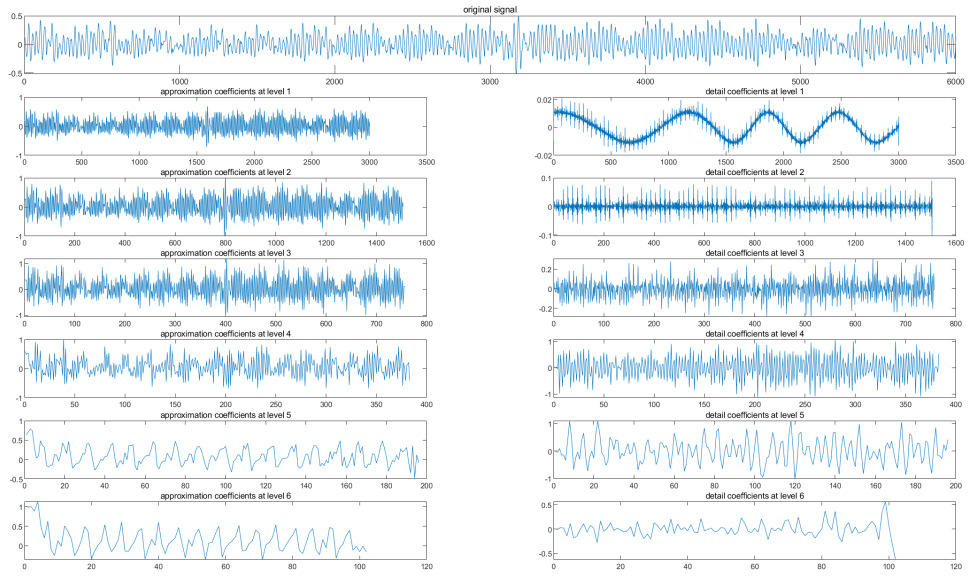
- **wavelet1hr.m** with **data1night.txt**

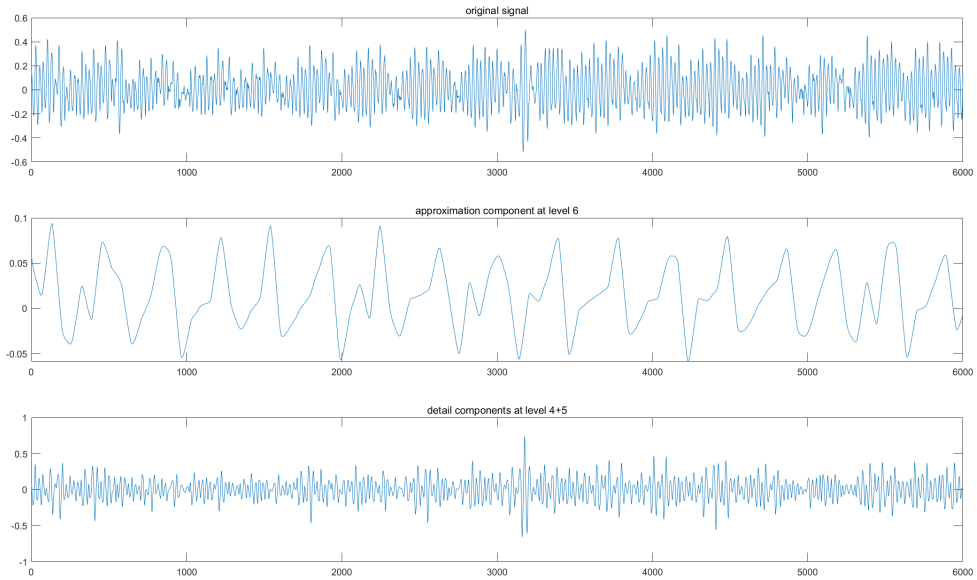




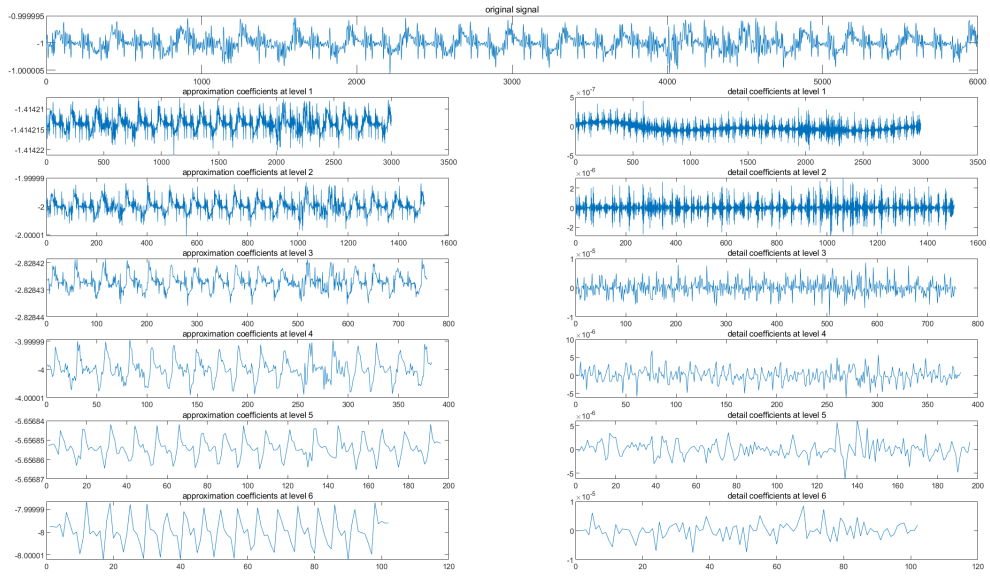
- **wavelet1min.m**

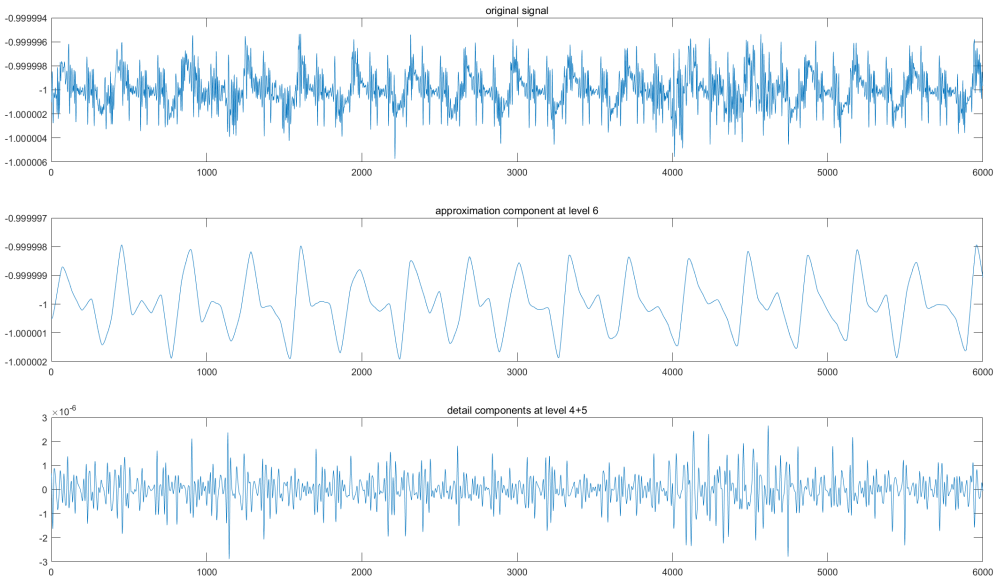
- **wavelet1min.m** with **data1min1.dat**





- **wavelet1min.m** with **data1min2.dat**





2. Find an optimal mother wavelet for signal separation

In this homework, we will use **wavelet1hr.m** sample code and **data1hr.txt** sample data provided in **ReportKit.zip** to conduct experiments.

Since the sample code **wavelet1hr.m** is primarily based on the discrete wavelet transform (DWT), it is recommended that the following discrete wavelets be tested first:

- db4
- db6
- sym5
- coif3
- haar
- bior4.4 (Original code)
- bior3.5

In the **wavelet1hr.m**, change the value of **WAVELET_FUNC** to test different wavelets. **For example:**

```
% Test Daubechies 4 wavelets
WAVELET_FUNC = 'db4';
```

In order to compare the performance of different mother wavelet comprehensively, it is suggested to add some code to calculate the evaluation index (such as **MSE**, **SNR**, etc.) for quantitative analysis.

To test **Mean Squared Error (MSE)** and **Signal-to-Noise Ratio (SNR)**, the following code has been added below the sample code **wavelet1hr.m**:

```
% Reconstruct the full signal from coefficients c and l
reconstructed_signal = waverec(c, l, WAVELET_FUNC);

% Calculate Mean Squared Error (MSE)
mse = mean((data - reconstructed_signal).^2);

% Calculate Signal-to-Noise Ratio (SNR)
signal_power = mean(data.^2);
noise_power = mse;
snr_value = 10 * log10(signal_power / noise_power);

% End timing and calculate elapsed time
elapsed_time = toc;

% Display results
disp(['Wavelet function: ', WAVELET_FUNC]);
disp(['Mean Squared Error (MSE): ', num2str(mse)]);
disp(['Signal-to-Noise Ratio (SNR): ', num2str(snr_value), ' dB']);
disp(['Elapsed time: ', num2str(elapsed_time), ' seconds']);
```

After running the modified sample code **wavelet1hr.m**, the MATLAB command window will display. **For example:**

```
Wavelet function: db4
Mean Squared Error (MSE): 6.5645e-26
Signal-to-Noise Ratio (SNR): 229.7855 dB
Elapsed time: 5.2891 seconds
```

Here is a table summarizing all the results:

Wavelet Function	MSE	SNR	Elapsed Time (seconds)
db4	6.5645e-26	229.7855 dB	5.2891
db6	4.3642e-26	231.5585 dB	4.8790

Wavelet Function	MSE	SNR	Elapsed Time (seconds)
sym5	1.2062e-27	247.1433 dB	5.3319
coif3	1.2072e-26	237.1398 dB	5.1025
haar	2.5747e-33	303.8503 dB	5.0412
bior4.4	4.1153e-26	231.8136 dB	5.6341
bior3.5	3.5893e-33	302.4074 dB	5.3629

Analysis of Results

Mean Squared Error (MSE)

- Lower MSE indicates a smaller difference between the original and reconstructed signals, which is desirable.
- Ranking (from lowest to highest MSE):
    1. **haar:** 2.5747e-33
    2. **bior3.5:** 3.5893e-33
    3. **sym5:** 1.2062e-27
    4. **coif3:** 1.2072e-26
    5. **db6:** 4.3642e-26
    6. **bior4.4:** 4.1153e-26
    7. **db4:** 6.5645e-26

Signal-to-Noise Ratio (SNR)

- Higher SNR indicates a better quality of the reconstructed signal, with less noise.
- Ranking (from highest to lowest SNR):
    1. **haar:** 303.8503 dB
    2. **bior3.5:** 302.4074 dB
    3. **sym5:** 247.1433 dB
    4. **coif3:** 237.1398 dB
    5. **bior4.4:** 231.8136 dB
    6. **db6:** 231.5585 dB
    7. **db4:** 229.7855 dB

Elapsed Time

- Lower elapsed time indicates higher computational efficiency.
- Ranking (from fastest to slowest):
    1. **db6:** 4.8790 seconds
    2. **haar:** 5.0412 seconds
    3. **coif3:** 5.1025 seconds
    4. **db4:** 5.2891 seconds
    5. **sym5:** 5.3319 seconds
    6. **bior3.5:** 5.3629 seconds

7. **bior4.4:** 5.6341 seconds

Determining the Best Mother Wavelet

Based on the above analysis, we can consider the following factors:

Performance Metrics

- MSE and SNR are critical indicators of the reconstruction quality.
- The **Haar wavelet**(haar) has the lowest MSE and highest SNR, followed closely by the **Biorthogonal 3.5 wavelet**(bior3.5).

Computational Efficiency

- All wavelets have similar computational times, with differences of less than a second.
- The db6 wavelet is the fastest, but the time differences are minimal and may not significantly impact overall performance.

Suitability for Signal Characteristics

1. Haar Wavelet (haar):
    - Advantages:
        - Simplest wavelet, capable of detecting sudden changes or discontinuities in the signal.
        - Excellent performance in terms of MSE and SNR in this test.
    - Disadvantages:
        - Lacks smoothness, which may not capture the signal's subtle features effectively.
        - May not be ideal for signals that require capturing smooth variations.
2. Biorthogonal Wavelet (bior3.5):
    - Advantages:
        - Provides symmetry and linear phase, which is beneficial for signal reconstruction.
        - High performance in MSE and SNR, close to that of the Haar wavelet.
    - Disadvantages:
        - Slightly slower than some other wavelets.
3. Symlets Wavelet (sym5):
    - Advantages:
        - Good balance between localization in time and frequency.
        - Better at capturing smooth features compared to Haar wavelet.
    - Performance:
        - Lower MSE and higher SNR compared to db4, db6, and coif3.
        - Slightly lower performance than Haar and Biorthogonal 3.5 in terms of MSE and SNR.

Practical Considerations

- Nature of the Signal:

    - If the signal contains sharp discontinuities or abrupt changes, the Haar wavelet may be appropriate.
    - If the signal is smooth or contains important frequency components that require higher-order analysis, wavelets like **sym5** or **bior3.5** may be more suitable.

- Reconstruction Quality vs. Signal Features:

    - While Haar shows the lowest MSE and highest SNR, it may oversimplify the signal due to its piecewise constant nature.
    - Biorthogonal and Symlets wavelets can capture more nuanced features of the signal, potentially providing better signal separation in practical applications.

Conclusion

Based on the test results and considering both quantitative metrics and signal characteristics, the **Biorthogonal 3.5 wavelet** (bior3.5) appears to be the best mother wavelet for the signal separation.

- It offers an excellent balance between reconstruction accuracy and the ability to capture signal features:
    - Second-lowest MSE (3.5893e-33).
    - Second-highest SNR (302.4074 dB).
    - Provides symmetry and linear phase properties, which are beneficial for signal analysis and reconstruction.
- While the Haar wavelet has the lowest MSE and highest SNR, its simplicity may not capture all the essential features of the signal, especially if the signal contains smooth variations.