Homework - Topic 3:

Detection of Biosignatures

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1. Implement at least two of the following algorithms for detection of characteristic points in separated pulse component signal

In this homework, we weill implementing two algorithms: **Wavelet Transform Method** and **Differentiation Method** to detect characteristic points in separated pulse component signals.

The experiment will reconstruct the codes of the two algorithms on the basis of sample code **walvetconfirm.m**, and test them based on sample data **data1min1.dat**.

Wavelet Transform Method

- **Algorithm Overview:** Wavelet Transform decomposes a signal into components at different frequency levels, allowing the extraction of specific features. The bior4.4 wavelet function was chosen for its ability to balance signal approximation and detail retention.
- **Implementation Details:**
  - The signal was decomposed into six levels using the Discrete Wavelet Transform.
  - Detail coefficients from levels 4 and 5 were extracted and denoised using soft thresholding.
  - The reconstructed signal, combining denoised components, was enhanced by squaring its values to amplify peaks.
- **Peak Detection:**
  - Peaks were detected using the **findpeaks** function, with thresholds based on the mean and standard deviation of the enhanced signal. Parameters like **MinPeakHeight** and **MinPeakDistance** were tuned to optimize detection.

Differentiation Method

- **Algorithm Overview:**
  - Differentiation emphasizes sudden changes in a signal by computing its first derivative, making it suitable for detecting rapid transitions indicative of characteristic points.
- **Implementation Details:**
  - The first derivative of the signal was calculated.
  - The derivative was enhanced by taking the absolute value, and peaks were detected similarly to the Wavelet Transform Method.

2. Compare their performance using proper measures in the previous slide

Performance Evaluation

- **Metrics Used:**
  - Accuracy
  - Sensitivity (Recall)
  - Specificity
  - Positive Predictivity (Precision)
  - Negative Predictivity
- **Actual Peak Determination:**
  - Actual characteristic points were manually labeled using MATLAB's data cursor tool and verified against the signal's visible features. A tolerance window of ±5 samples was used to match detected and actual peaks.

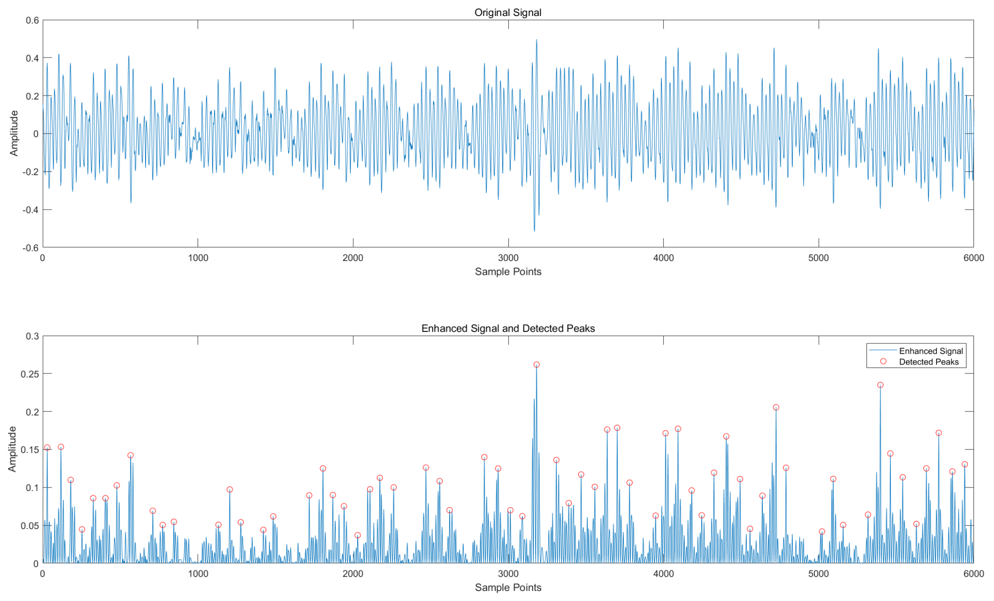
Results

- **Detection Outcomes**
  - **Wavelet Transform Method:**
    - Detected 81 characteristic points.
    - Successfully aligned with all actual peaks, indicating no false negatives.
  - **Differentiation Method:**
    - Detected 88 characteristic points.
    - Also achieved perfect alignment with actual peaks, indicating no false negatives.
- **Performance Metrics**

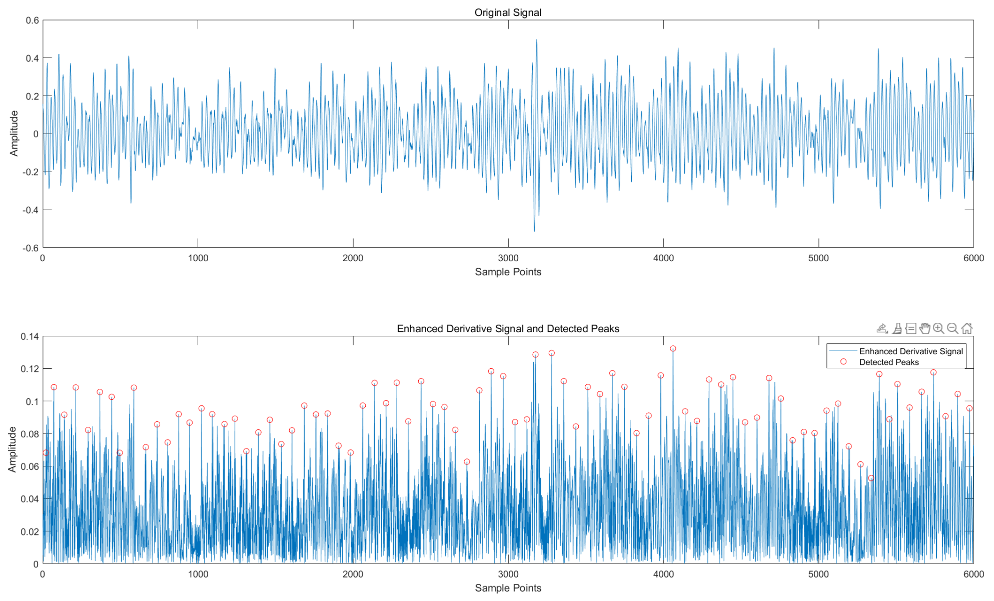
Metric	Wavelet Transform	Differentiation
Accuracy (%)	99.07	98.82
Sensitivity (%)	100.00	100.00
Specificity (%)	99.07	98.81
Positive Predictivity (%)	11.11	12.35
Negative Predictivity (%)	100.00	100.00

- **Visual Comparison:**

- **Wavelet Transform Method**



- **Differentiation Method**



Result Analysis

- **High Sensitivity:** Both methods achieved 100% sensitivity, indicating that all actual characteristic points were detected without any omissions. This highlights the algorithms' robustness in avoiding false negatives.
- **Low Positive Predictivity:** Despite high sensitivity, the positive predictivity values were low (11.11% and 12.35%), reflecting a significant number of false positives. This could result from overly permissive thresholds or the lack of filtering in preprocessing.
- **Specificity and Accuracy:** Both methods demonstrated high specificity (over 98%) and overall accuracy (over 98%), suggesting reliable performance in distinguishing non-characteristic regions.

Wavelet Transform Method:

- Effective in enhancing signal features and reducing noise through multilevel decomposition.
- Requires computational overhead due to wavelet decomposition and reconstruction.

Differentiation Method:

- Simpler and computationally less intensive.
- More susceptible to noise, leading to a slightly higher false positive rate.

Appendices: MATLAB codes

1. **Wavelet Transform Method:**

```
% Clear workspace and command window
clear; clc;

% Load the original signal
[data_file, data_path] = uigetfile('*.dat', 'Select a data file'); % Open file
dialog
data = load([data_path, data_file]);  % Load 1-minute pressure data
lendata = length(data);
data = (data - 2^16/2) / (2^16/2); % Convert range from 0-65535 to -0.5 to +0.5

% Define wavelet function
waveletfunc = 'bior4.4';

% Perform 6-level wavelet decomposition using the defined wavelet
[c, l] = wavedec(data, 6, waveletfunc);

% Extract detail coefficients at level 4 and level 5
cd4 = detcoef(c, l, 4);
cd5 = detcoef(c, l, 5);

% Denoise cd4 and cd5
thrfactor = 0.1;
thr5 = std(cd5) * thrfactor;
cd5x = wthresh(cd5, 's', thr5);
thr4 = std(cd4) * thrfactor * 2;
cd4x = wthresh(cd4, 's', thr4);

% Reconstruct detail components from the denoised coefficients
d4x = wrcoef('d', c, l, waveletfunc, 4);
d5x = wrcoef('d', c, l, waveletfunc, 5);

% Combine detail components
reconstructed_signal = d4x + d5x;

% Enhance the signal (square)
enhanced_signal = reconstructed_signal .^ 2;

% Set threshold for peak detection
threshold = mean(enhanced_signal) + 0.5 * std(enhanced_signal);
```

```
% Find peaks in the enhanced signal
[peaks, locs] = findpeaks(enhanced_signal, 'MinPeakHeight', threshold,
'MinPeakDistance', 50);

% Plot the original signal and detected peaks
figure;
subplot(2,1,1);
plot(data);
title('Original Signal');
xlabel('Sample Points');
ylabel('Amplitude');

subplot(2,1,2);
plot(enhanced_signal);
hold on;
plot(locs, peaks, 'ro');
title('Enhanced Signal and Detected Peaks');
xlabel('Sample Points');
ylabel('Amplitude');
legend('Enhanced Signal', 'Detected Peaks');

% Display detected peak locations
disp('Detected peak locations (indices):');
disp(locs);

%% Performance evaluation

% Assume there is a vector of actual feature point locations
% Example actual feature points
actual_peaks = [29, 1132, 2172, 3389, 4325, 5397, 5941];

% Initialize counters
TP = 0;
FP = 0;
FN = 0;

tolerance = 5; % Define tolerance window

% Convert detected peaks and actual peaks to logical arrays
detected_array = zeros(1, length(data));
detected_array(locs) = 1;

actual_array = zeros(1, length(data));
actual_array(actual_peaks) = 1;

% Calculate TP and FN
for i = 1:length(actual_peaks)
    window_start = max(actual_peaks(i) - tolerance, 1);
    window_end = min(actual_peaks(i) + tolerance, length(data));
    if any(detected_array(window_start:window_end))
        TP = TP + 1;
    else
        FN = FN + 1;
    end
end

% Calculate FP
for i = 1:length(locs)
    window_start = max(locs(i) - tolerance, 1);
    window_end = min(locs(i) + tolerance, length(data));
    if ~any(actual_array(window_start:window_end))
        FP = FP + 1;
    end
end

% Total negatives
Total_Negatives = length(data) - length(actual_peaks);

% Calculate TN
TN = Total_Negatives - FP;

% Compute performance metrics
Accuracy = (TP + TN) / (TP + TN + FP + FN);
Sensitivity = TP / (TP + FN);
Specificity = TN / (TN + FP);
Positive_Predictability = TP / (TP + FP);
Negative_Predictability = TN / (TN + FN);

% Display results
fprintf('\nPerformance Metrics (Wavelet Transform Method):\n');
fprintf('Accuracy: %.2f%%\n', Accuracy * 100);
fprintf('Sensitivity: %.2f%%\n', Sensitivity * 100);
fprintf('Specificity: %.2f%%\n', Specificity * 100);
fprintf('Positive Predictability: %.2f%%\n', Positive_Predictability * 100);
fprintf('Negative Predictability: %.2f%%\n', Negative_Predictability * 100);
```

2. **Differentiation Method:**

```
% Clear workspace and command window
clear; clc;

% Load the original signal
[data_file, data_path] = uigetfile('*.dat', 'Select a data file'); % Open file
dialog
data = load([data_path, data_file]);  % Load 1-minute pressure data
lendata = length(data);
data = (data - 2^16/2) / (2^16/2); % Convert range from 0-65535 to -0.5 to +0.5

% Compute the first derivative of the signal
diff_data = diff(data);

% Enhance the derivative signal (take absolute value)
enhanced_diff = abs(diff_data);
```

```
% Set threshold for peak detection
threshold = mean(enhanced_diff) + 0.5 * std(enhanced_diff);

% Find peaks in the enhanced derivative signal
[peaks, locs] = findpeaks(enhanced_diff, 'MinPeakHeight', threshold,
'MinPeakDistance', 50);

% Adjust locs because the length reduces by 1 after diff
locs = locs + 1;

% Plot the original signal and detected peaks
figure;
subplot(2,1,1);
plot(data);
title('Original Signal');
xlabel('Sample Points');
ylabel('Amplitude');

subplot(2,1,2);
plot(enhanced_diff);
hold on;
plot(locs - 1, peaks, 'ro');
title('Enhanced Derivative Signal and Detected Peaks');
xlabel('Sample Points');
ylabel('Amplitude');
legend('Enhanced Derivative Signal', 'Detected Peaks');

% Display detected peak locations
disp('Detected peak locations (indices):');
disp(locs);

%% Performance evaluation

% Assume there is a vector of actual feature point locations
% Example actual feature points
actual_peaks = [21, 588, 806, 1607, 2439, 3280, 4061, 4140, 5740, 5972];

% Initialize counters
TP = 0;
FP = 0;
FN = 0;

tolerance = 5; % Define tolerance window

% Convert detected peaks and actual peaks to logical arrays
detected_array = zeros(1, length(data));
detected_array(locs) = 1;

actual_array = zeros(1, length(data));
actual_array(actual_peaks) = 1;

% Calculate TP and FN
for i = 1:length(actual_peaks)
    window_start = max(actual_peaks(i) - tolerance, 1);
    window_end = min(actual_peaks(i) + tolerance, length(data));
    if any(detected_array(window_start:window_end))
        TP = TP + 1;
    else
        FN = FN + 1;
    end
end

% Calculate FP
for i = 1:length(locs)
    window_start = max(locs(i) - tolerance, 1);
    window_end = min(locs(i) + tolerance, length(data));
    if ~any(actual_array(window_start:window_end))
        FP = FP + 1;
    end
end

% Total negatives
Total_Negatives = length(data) - length(actual_peaks);

% Calculate TN
TN = Total_Negatives - FP;

% Compute performance metrics
Accuracy = (TP + TN) / (TP + TN + FP + FN);
Sensitivity = TP / (TP + FN);
Specificity = TN / (TN + FP);
Positive_Predictability = TP / (TP + FP);
Negative_Predictability = TN / (TN + FN);

% Display results
fprintf('\nPerformance Metrics (Differentiation Method):\n');
fprintf('Accuracy: %.2f%%\n', Accuracy * 100);
fprintf('Sensitivity: %.2f%%\n', Sensitivity * 100);
fprintf('Specificity: %.2f%%\n', Specificity * 100);
fprintf('Positive Predictability: %.2f%%\n', Positive_Predictability * 100);
fprintf('Negative Predictability: %.2f%%\n', Negative_Predictability * 100);
```