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DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 4602

Signals and Systems Lab

Project: Heart Rate Variability (Analysis of an ECG signal) Using MATLAB

Group Members:

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The project aims to analyze electrocardiogram (ECG) signals using MATLAB. Electrocardiogram (ECG) signals are essential diagnostic tools in cardiology, providing critical information about cardiac electrical activity. Real-time processing techniques play a crucial role in extracting valuable insights from ECG signals, particularly in identifying R points (representing ventricular depolarization) and assessing heart rate variability (HRV).

Methodology:

The raw ECG data is read from a file ('100.dat') using MATLAB's file input-output functions.

Filtering: Low-pass and high-pass Butterworth filters are applied to remove noise and artifacts from the ECG signal.

Peak Detection: R-peaks are detected using the 'findpeaks' function to segment the ECG signal.

Heart Rate Analysis: NN intervals are computed from R-peaks, and metrics such as RMSSD and SDNN are calculated to assess heart rate variability.

Power Spectral Density (PSD) Estimation: Welch's method is employed to compute the PSD of the filtered ECG signal.

Rhythm Disturbance Detection: Thresholds for RMSSD and SDNN are defined to detect rhythm disturbances in the ECG signal.

Normalization: The amplitude of the filtered ECG signal is normalized to a range of [-1, 1] for standardization and comparative analysis.

Data Acquisition and Preprocessing:

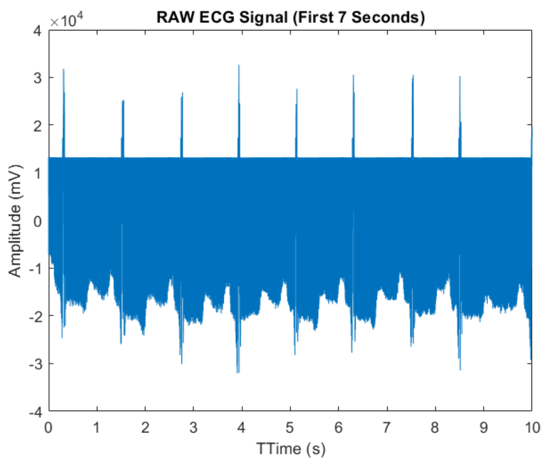
The ECG signal is acquired from the file '100.dat' using MATLAB's file input/output functions. The file is read using the ‘fread’ function and stored in the variable **‘ecg signal’.**

Sampling frequency (fs) is set to 360 Hz, and a time vector 't' is generated to represent the time axis corresponding to the ECG signal.

A plot is generated to visualize the characteristics of the raw signal, spanning the first 10 seconds of the ECG data.

```
filename = '100.dat';
fid = fopen(filename, 'r');
ecg_signal = fread(fid, Inf, 'int16');
fclose(fid);
```

```
%Extract sampling frequency and time vector
fs = 360;
t = (0:length(ecg_signal)-1)/fs;

figure;
t_7sec = t(t<=10); %Adjust ime vector to only span first 7 seconds
plot(t_7sec, ecg_signal(1:length(t_7sec)));
xlabel('TTime (s)');
ylabel('Amplitude (mV)');
title('RAW ECG Signal (First 7 Seconds)');
```



Thus, the signal obtained is the 'RAW ECG signal' which we have used for further modifications and extractions.

Filtering for Noise Reduction:

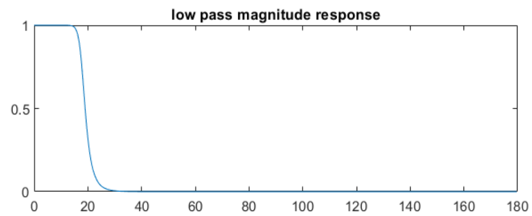
Digital filtering techniques are employed to enhance signal quality and remove undesirable components such as baseline wander, noise, and movement artifacts.

1. **Low Pass Filter:**

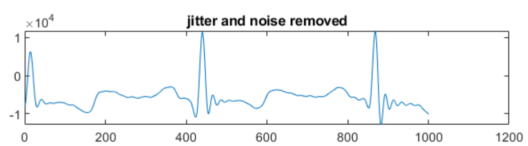
The raw ECG signal has a lot of noise with very high frequency. Hence to remove the noise, a low pass filter has been applied. A Butterworth low-pass filter is applied to attenuate high-frequency noise components using the **'butter'** function. The filter order has been selected as 10 and the cut off frequency has been selected as 18 after trial and error by observing the figure. Initially a matrix [b,a] has been formed which indicates the co-efficient of the transfer function of the filter matrix. Then the frequency response and the normalized frequency response has been taken in the [h,w] matrix using the **freqz** function.

This low pass filter has been applied to the ECG signal using 'filter ' function.

```
fs=360;
filter_order=10;
cuttoff_freq=18;
[b,a]= butter(filter_order, cuttoff_freq/(fs/2), 'low');
[h,w] = freqz(b,a);
figure(2)
subplot(2,1,1)
plot(w/pi*fs/2, abs(h), '-')
title ( 'low pass magnitude response')
```



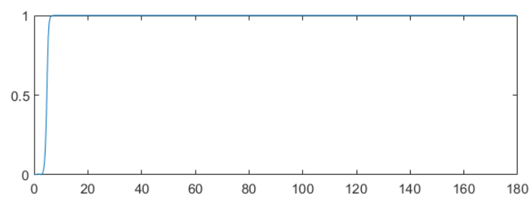

```
low_pass= filter(b,a,ecg_signal);
figure(3)
subplot(3,1,2)
plot(low_pass(1000:2000))
title('jitter and noise removed')
```



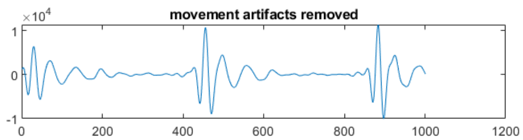
The output signal can be observed to be a lot cleaner than the raw signal. However, some low frequency noise can still be observed, for which we will use the high pass filter.

2. **High Pass Filter:**
   The high pass filter has been created the same way as the low pass filter with a cut off frequency of 5. The filtered signal **'high_pass'** is the desired ECG signal with which we will further work for extracting features.

```
fs= 360;
filter_order=10;
cutoff_freq2= 5;
[b,a]= butter(filter_order, cutoff_freq2/(fs/2), 'high');
[h,w] = freqz(b,a);
figure(3)
subplot(2,1,2)
plot(w/pi*fs/2, abs(h), '-')
```




```
high_pass=filter(b,a,low_pass);
figure(4)
subplot(3,1,3)
plot(high_pass(1000:2000))
title('movement artifacts removed')
```



R Peak Detection:

R peak detection is performed using a peak detection algorithm to identify R peaks in the filtered ECG signal. Here the peaks have been determined using **'findpeaks'** function and have been plotted by overlapping over the main signal 'high_pass'.
From the R peak locations, NN intervals (time intervals between successive R peaks) are calculated.

HRV Analysis:

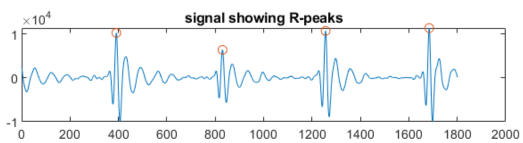
HRV analysis involves computing metrics such as RMSSD (Root Mean Square of Successive Differences) and SDNN (Standard Deviation of NN intervals) to assess autonomic nervous system modulation.

NN Intervals (NNI): NN intervals represent the time intervals between successive R-peaks in an ECG signal, also known as Normal-to-Normal intervals. These intervals reflect the beat-to-beat variability of the heart rate. They provide information about the timing of individual heartbeats and the overall heart rate dynamics.

RMSSD (Root Mean Square of Successive Differences): RMSSD is a time-domain HRV metric that quantifies the variability in consecutive NN intervals. It is calculated by taking the square root of the mean of the squared differences between adjacent NN intervals. RMSSD primarily reflects parasympathetic (vagal) activity on the heart, particularly high-frequency variations associated with respiratory sinus arrhythmia. Higher RMSSD values indicate greater beat-to-beat variability and are often associated with increased parasympathetic activity and better cardiovascular health.

SDNN (Standard Deviation of NN Intervals): SDNN is another time-domain HRV metric that quantifies the overall variability in NN intervals. It is calculated as the standard deviation of all NN intervals within a given period. SDNN reflects both sympathetic and parasympathetic influences on heart rate variability, as well as other factors contributing to overall heart rate variability. Higher SDNN values generally indicate greater overall variability in heart rate and are associated with better cardiovascular health.

```
% Detect R-peaks for segmentation
[val, r_locs] = findpeaks(high_pass(200:2000), 'MinPeakHeight', 0.5*10^4);
plot(1:length(high_pass(200:2000)), high_pass(200:2000), r_locs, val, 'o')
title('signal showing R-peaks')
```




```
% Calculating NN intervals
nn_intervals = diff(r_locs)
```

```
nn_intervals = 3×1
   439
   426
   428
```

```
% Determination of RMSSD and SDNN
rmssd = sqrt(mean(diff(nn_intervals).^2));
sdnn = std(nn_intervals);
disp(['RMSSD: ', num2str(rmssd)]);
```

```
RMSSD: 9.3005
```

```
disp(['SDNN: ', num2str(sdnn)]);
```

```
SDNN: 7
```

```
% Number of beats in signal
num_beats = length(r_locs);
fprintf('Number of beats in signal: %d\n', num_beats);
```

```
Number of beats in signal: 4
```

Heart Rate Monitoring:

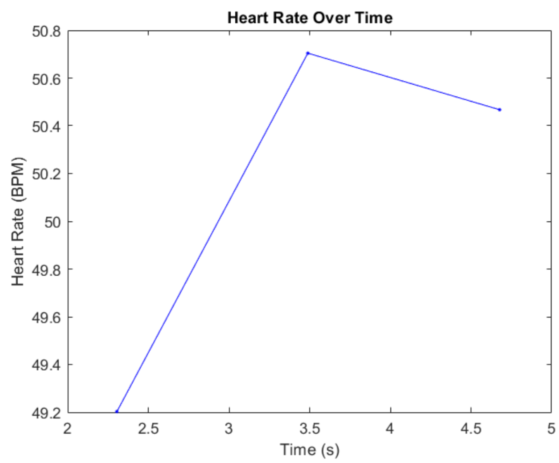
Heart Rate Calculation: The NN intervals are used to calculate the heart rate. Heart rate is typically calculated by taking the inverse of the average NN interval and multiplying by 60 to convert from seconds to beats per minute (BPM). This calculation provides the heart rate at each R-peak, giving us a series of heart rate values over time.

The heart rate values calculated at each R-peak are plotted against the corresponding time stamps. This results in a graph where the x-axis represents time (in seconds) and the y-axis represents heart rate (in BPM). Each point on the graph represents the heart rate at a specific time, reflecting the variation in heart rate over the duration of the signal.

```
% Heart rate
heart_rate = 60 ./ (mean(nn_intervals) / fs);
disp(['Heart Rate (BPM): ', num2str(heart_rate)]);
```

```
Heart Rate (BPM): 50.116
```

```
% Plot heart rate over time
t_hr = r_locs / fs;  % Time stamps corresponding to R-peaks
figure;
plot(t_hr(2:end), 60 ./ (nn_intervals / fs), 'b.-');  % Convert NN intervals to
heart rate (BPM)
xlabel('Time (s)');
ylabel('Heart Rate (BPM)');
title('Heart Rate Over Time');
```



Rhythm Disturbance Detection:

Threshold-based analysis is employed to detect potential rhythm disturbances based on predefined threshold values of HRV metrics such as RMSSD and SDNN.

The threshold values for RMSSD in a healthy adult is 16 to 107 ms and the threshold values for SDNN in a healthy adult is 50-100 ms. By comparing the values of rmssd and sdnn that we got from our ECG signal with these threshold values, we can detect if there is any rhythm disturbances or not. Deviations from these thresholds may indicate abnormalities in cardiac rhythm, warranting further clinical evaluation.

Significance:

Higher RMSSD and SDNN values generally indicate greater overall variability in heart rate and are associated with better cardiovascular health. But if RMSDD and SDNN values are very much higher in a patient with heart complications, it may increase the risk of heart dysfunctionalities but otherwise higher values of these HRV metrics doesn't indicate any harm.

```
% Check for rhythm disturbances based on threshold values
rmssd_threshold_low= 16;
rmssd_threshold_high= 107
```

```
rmssd_threshold_high = 107
```

```
sdnn_threshold_high = 100;
sdnn_threshold_low = 50
```

```
sdnn_threshold_low = 50
```

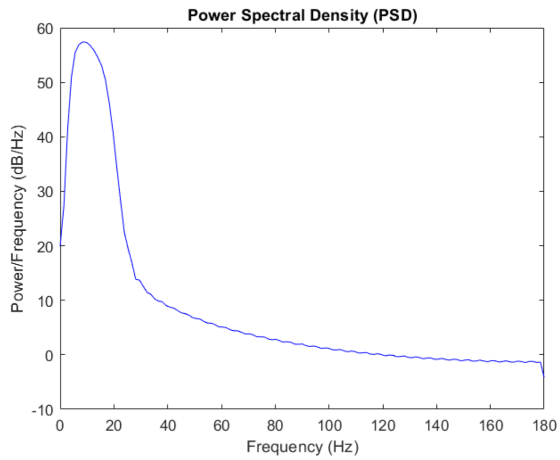
```
if rmssd < rmssd_threshold_low ||rmssd > rmssd_threshold_high|| sdnn <
sdnn_threshold_low || sdnn> sdnn_threshold_high
    disp('Rhythm disturbance detected!');
else
    disp('No rhythm disturbance detected.');
end
```

```
Rhythm disturbance detected!
```

Frequency Domain Analysis:

Power spectral density (PSD) analysis is conducted to investigate the frequency components of the ECG signal.
The PSD plot illustrates the distribution of power across different frequency bands, aiding in the characterization of cardiac rhythm and frequency characteristics.

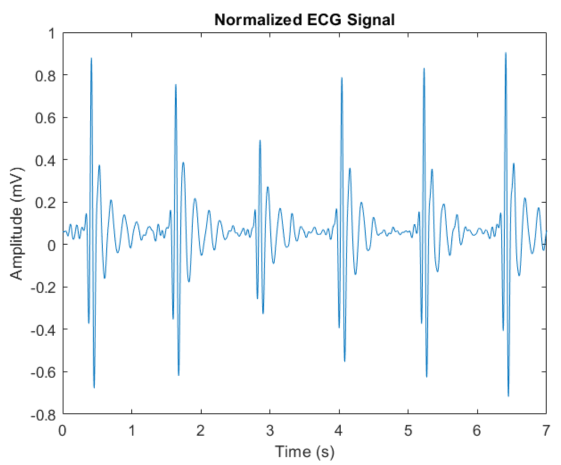
```
%power spectral density
win_length = round(0.5 * fs);  % Window length for PSD estimation (half-
second window)
overlap = round(0.25 * fs);     % Overlap between consecutive windows
[psd, f] = pwelch(high_pass(200:2000), hamming(win_length), overlap, [], fs);

% Plot PSD
figure;
plot(f, 10*log10(psd), 'b');
xlabel('Frequency (Hz)');
ylabel('Power/Frequency (dB/Hz)');
title('Power Spectral Density (PSD)');
```



Normalizing the filtered ECG signal:

It normalizes the amplitude of the filtered ECG signal (‘high_pass’) to the range [-1, 1]. The normalization process involves subtracting the minimum value of the filtered signal and dividing by the range of the signal (difference between maximum and minimum values). After normalization, the signal is scaled to span the range [-1, 1].

```
% Normalize amplitude of filtered ECG signal to range [-1, 1]
normalized_signal = (high_pass - min(high_pass)) / (max(high_pass) -
min(high_pass)) * 2 - 1;
```




```
% Plot the normalized ECG signal
figure;
t_7sec = t(t<=7); % Adjust time vector to only span first 7 seconds
plot(t_7sec, normalized_signal(1:length(t_7sec)));
xlabel('Time (s)');
```

```
ylabel('Amplitude (mV)');
title('Normalized ECG Signal');
```

Results:

Features of ECG signal: Plots are generated to visualize the raw ECG signal, filtered signals, R-peaks, heart rate over time, and the normalized ECG signal.
HRV metrics: Heart rate variability metrics (RMSSD, SDNN) are computed, and rhythm disturbances are detected based on predefined thresholds.
Frequency Analysis: The Power Spectral Density (PSD) plot provides insights into the frequency distribution of signal power.

The project successfully demonstrated the analysis of ECG signals using MATLAB, encompassing various stages from signal processing to visualization and interpretation. The application of signal processing techniques and quantitative analysis methods provided valuable insights into cardiac dynamics and rhythm disturbances. Future work may involve further optimization of algorithms and exploration of advanced signal processing techniques for comprehensive ECG analysis.

Contributions:

200021304: Low-Pass Filtering, High-Pass Filtering, R-Peak Detection, Report Writing

200021312: PSD, Normalized ECG Signal, Presentation Preparation, Report Writing

200021330: HRV metrics (NN intervals, RMSDD, SDNN, heart beats), Heart Rate Analysis, Rhythm Disturbance Detection, Report Writing

200021333: Load Raw ECG Signal, Presentation Preparation, Report Writing