Faculty of Engineering & Technology Electrical & Computer Engineering Department

ENCS4310 |Digital Signal Processing|

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Project

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Abstract

This project involves processing real electrocardiographic (ECG) signals by applying low-pass and high-pass filtering techniques to data sampled at 360 Hz. The tasks include visualizing the raw data, calculating transfer functions and frequency responses for the filters, and applying these filters to improve signal readability and enable automatic peak detection and classification. The project also explores the impact of filter order on the results and includes a bonus challenge of using adaptive filters for noise removal. The final report should include a comprehensive analysis, results, and well-documented code.

Table of Contents

Table Of Figures

Theory

Filtering electrocardiographic (ECG) signals involves the application of high-pass and low-pass filters to remove noise and improve signal quality. The high-pass filter eliminates low-frequency noise, such as baseline wander, while the low-pass filter removes high-frequency noise, such as muscle artifacts. This dual-stage filtering process enhances the readability of the ECG signals, facilitating subsequent peak detection and classification. Understanding the frequency response and characteristics of these filters is crucial for their effective application in signal processing.

Procedure

Part 1: Data Visualization

1.1 Insert the real-time column for each signal:

By using import Data from homepage in Matlab, we renamed the name of each column, then we select each needed column, we Import Selection to output type: Column vectors as shown below:

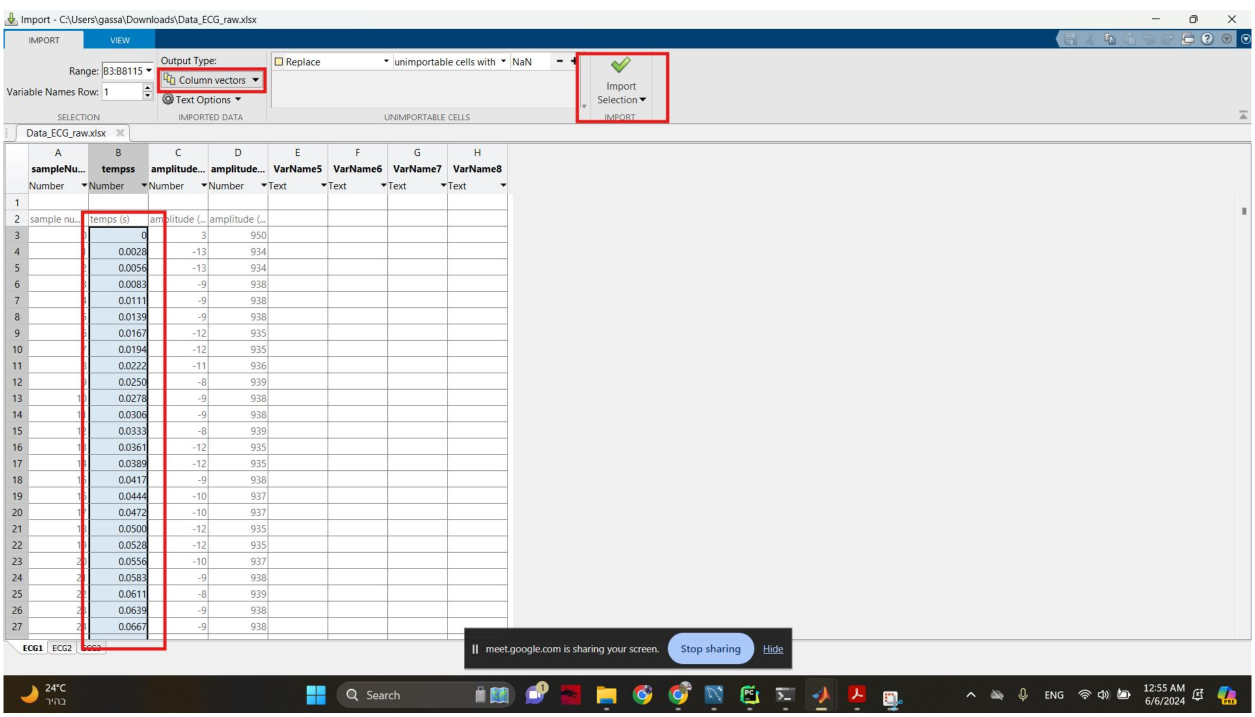

Figure 1 - Insert Data

1.2 Display each of these signals (reduce the width of the display lines for better readability):

Using Matlab, we run the code below:

```
t_5sec1=temp_ECG1.*(temp_ECG1<5);
t_5sec2=temp_ECG2.*(temp_ECG2<5);

%Figure of positive Amplituide (ECG1) in full period and five second
figure ;

subplot(2, 1, 1);
plot(temp_ECG1,A2_ECG1 );
title('ECG 1 ');
xlabel('time in full time');
ylabel('A');

subplot(2, 1, 2);
plot(t_5sec1, A2_ECG1 , '-r');
title('ECG 1');
xlabel('time of first 5 secons');
ylabel('A');

%%%%%%%%%%%%%%%%%%%
%Figure of minus Amplituide (ECG1) in full period and five second
figure ;

subplot(2, 1, 1);
plot(temp_ECG1,A_ECG1 );
title('ECG 1 minus amp ');
xlabel('time in full time');
ylabel(   );

subplot(2, 1, 2);
plot(t_5sec1, A_ECG1 , '-r');
title('ECG 1 minus amp');
xlabel('time of first 5 secons');
ylabel(   );

%%%%%%%%%%%%%%%%%%%
%Figure of positive Amplituide (ECG2) in full period and five second
figure ;

subplot(2, 1, 1);
plot(temp_ECG2,A2_ECG2 );
title('ECG 2 ');
xlabel('time in full time');
ylabel('A');

subplot(2, 1, 2);
plot(t_5sec2, A2_ECG2 , '-r');
title('ECG 2');
xlabel('time of first 5 secons');
ylabel(   );
```

```
%%%%%%%%%%%%
%Figure of minus Amplituide (ECG2) in full period and five second
figure;

subplot(2, 1, 1);
plot(temp_ECG2,A_ECG2 );
title('ECG 2 minus  amp');
xlabel('time in full time');
ylabel(   );

subplot(2, 1, 2);
plot(t_5sec2, A_ECG2 , '-r');
title('ECG 2 minus amp');
xlabel('time of first 5 secons');
ylabel('A');
```

After running the code we got these Matlab figures, each figure has a label name.

Objective:

The task was to visualize ECG signals from two datasets (ECG1 and ECG2) and display them with reduced line width for better readability. This included showing the entire signal duration as well as a zoomed-in view of the first 5 seconds to provide detailed insights.

1. Unnormalized signal ECG1 in full time and in first 5 seconds:

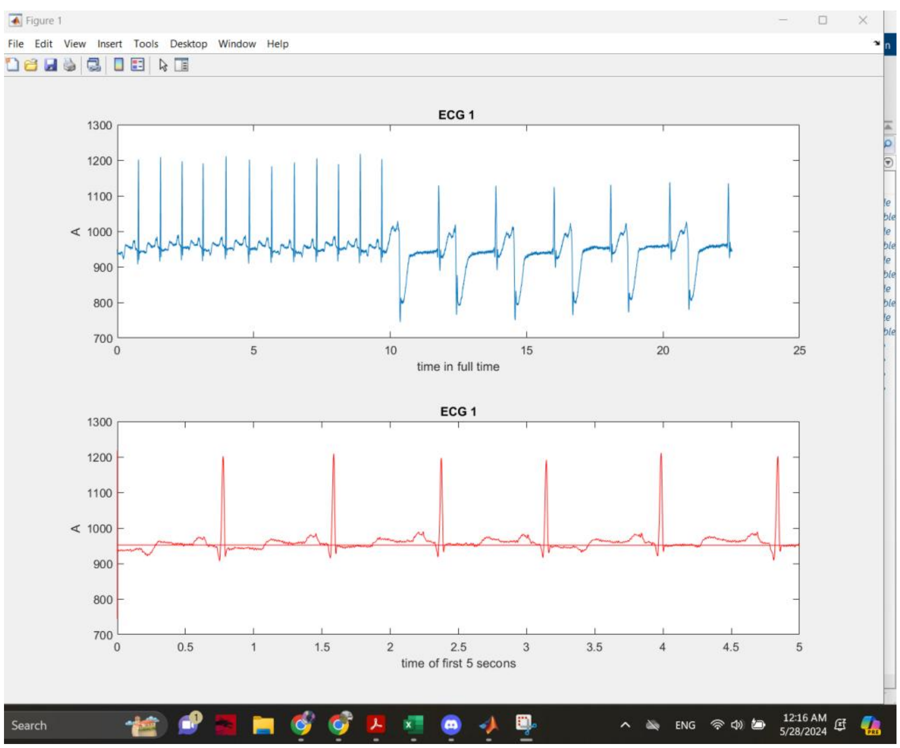

Figure 2 - Unnormalized signal ECG1

2. Normalized signal ECG1 in full time and in first five seconds:

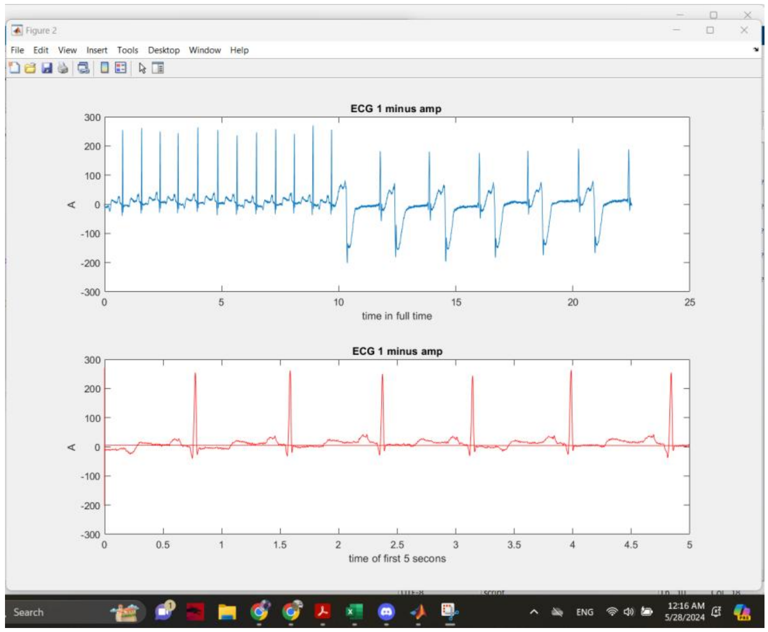

Figure 3 - Normalized signal ECG1

A. ECG1 Signal:

- **Full Duration:** The top plot shows the entire ECG1 signal clear visualization.
- **First 5 Seconds:** The bottom plot zooms into the first 5 seconds of the ECG1 signal, providing a detailed view of the initial part of the signal.

3. Unnormalized ECG 2 in full time and in first five seconds:

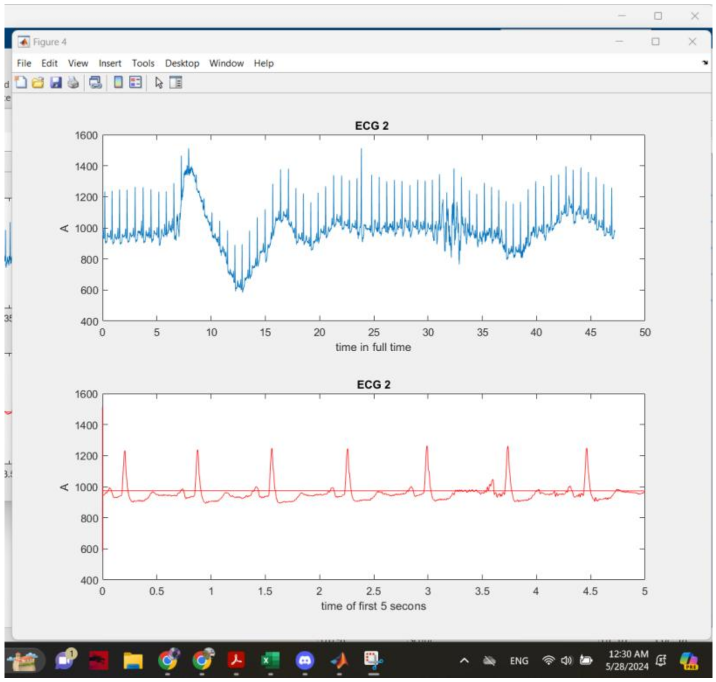

Figure 4 - Unnormalized signal ECG2

4. Normalized ECG 2 in full time and in first five seconds:

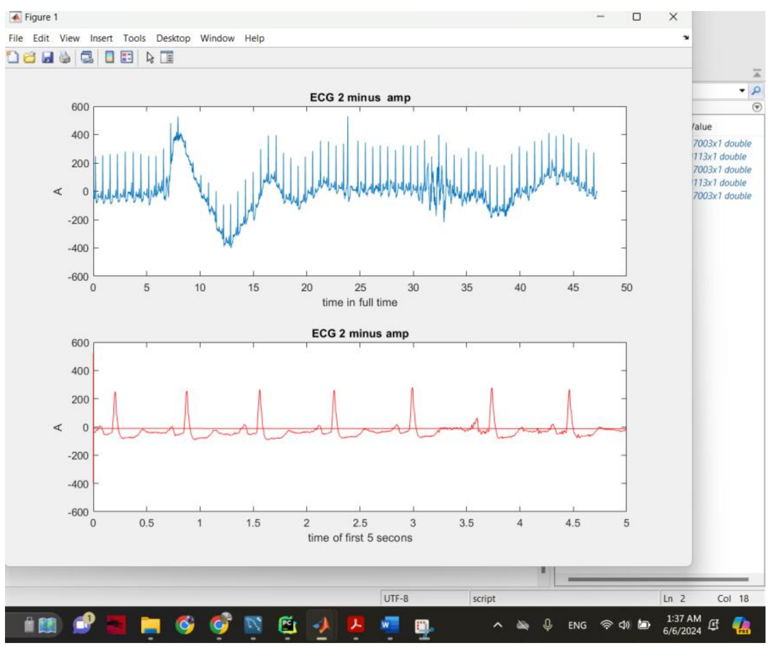

Figure 5 - Normalized signal ECG2

B. ECG2 Signal:

- **Full Duration:** Similar to ECG1, the top plot displays the full ECG2 signal.
- **First 5 Seconds:** The bottom plot focuses on the first 5 seconds of the ECG2 signal.

Conclusion for 1.2:

The ECG signals are displayed more clearly. This approach allows for better readability and easier identification of key features. The detailed visualization of the initial 5 seconds helps in closely examining the start of the signals, which is critical for detecting any anomalies or artifacts. The normalized amplitude plots further assist in comparing the signals on a consistent scale. These visualizations are essential for understanding the characteristics of the ECG signals and are foundational for subsequent signal processing steps, such as filtering and feature extraction.

1.3 What filtering types are necessary to improve the readability of data and make automatic processing possible:

To improve the readability of data and make automatic processing possible in the context of filtering electrocardiographic (ECG) signals, the following filtering types are necessary:

1. Low-pass Filter: This filter is used to remove high-frequency noise from the ECG signals. The low-pass filter allows only the signals below a certain cutoff frequency to pass through, smoothing the data and preserving the essential characteristics of the ECG signal.

2. High-pass Filter: This filter helps in removing low-frequency noise from the ECG signals. The high-pass filter allows only the signals above a certain cutoff frequency to pass, eliminating slow-varying components that can obscure the true cardiac signal.

Part 2: Filtering the ECG:

We will use two filters; the output of the high-pass filter is HP (n) and the low pass is LP (n). The input is X (n).

2.1 The high-pass filter:

HP (n) = HP (n − 1) - (1/32) X (n) + X (n−16) – X(n−17) + (1/32) X (n − 32)

- **Calculate its transfer function?**

$$HP(n) = HP(n-1) - \frac{1}{32} X(n) + X(n-16) - X(n-17) + \frac{1}{32} X(n-32)$$

$$Z\{HP(n)\} = z^{-1} HP(z) - \frac{1}{32} X(z) + z^{-16} X(z) + z^{-17} X(z) + \frac{z^{-32}}{32} X(z)$$

$$HP(z) - z^{-1} HP(z) = \left(-\frac{1}{32} + z^{-16} - z^{-17} + \frac{1}{32} z^{-32}\right) X(z)$$

$$HP(z)\left(1 - z^{-1}\right) = \left(-\frac{1}{32} + z^{-16} - z^{-17} + \frac{1}{32} z^{-32}\right) X(z)$$

$$H(z) = \frac{HP(z)}{X(z)} = \frac{-\frac{1}{32} + z^{-16} - z^{-17} + \frac{1}{32} z^{-32}}{1 - z^{-1}}$$

Figure 6 - Transfer function HP(n)

- **Find and plot the Frequency response?**

```
% Define the filter coefficients
a = [1, -1]; % Coefficients for the output HP(n)
b = [-1/32, zeros(1, 15), 1, -1, zeros(1, 14), 1/32]; % Coefficients for the
input X(n)

% Load your ECG signals (assuming they are stored in variables ECG1 and ECG2)
 ECG1 = A_ECG1;
 ECG2 = A_ECG2 ;

% Plot the frequency response
figure;
freqz(b, a, 1024);
title(                                            );
```

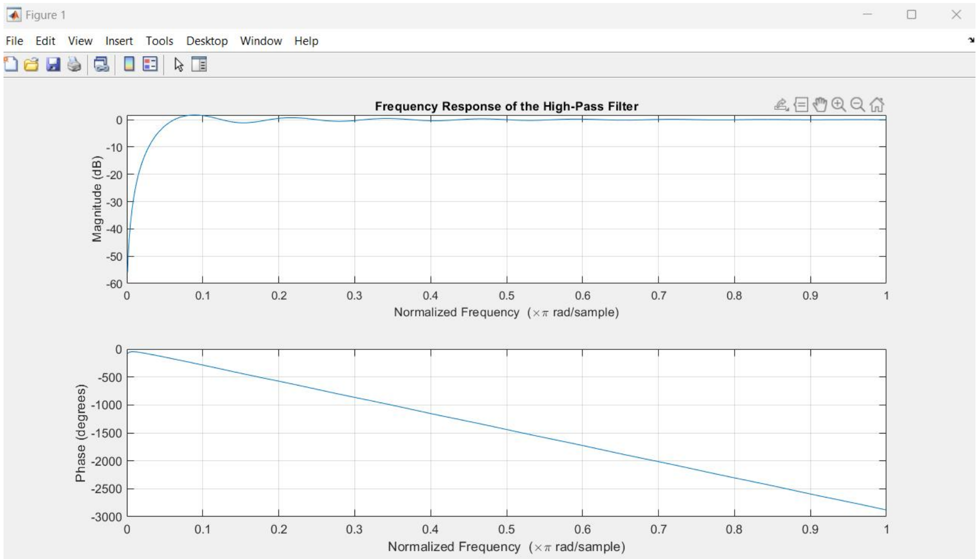

Figure 7 - Frequency response HP(n)

A. Magnitude Response:

The magnitude response plot shows how the amplitude of the output signal varies with frequency. For a high-pass filter, we expect the response to attenuate low frequencies and pass high frequencies.

B. Phase Response:

The phase response plot shows how the phase of the output signal varies with frequency. This is important for understanding the filter's effect on the phase of the input signal.

The constructed filter functions as a high-pass filter, successfully attenuating low-frequency components while permitting high-frequency components to pass through, as confirmed by the frequency response analysis. This behavior aligns with what is needed to eliminate low-frequency noise, such as baseline drift, from ECG readings. The plots assist the applicability of the filter for the intended application by clearly visualizing its properties.

- ## Which family does it belong to (FIR, IIR)?

FIR , where we can see in the above transfer function for high pass filter, we have pole in zero point but the zero of transfer function in same place so will not be IIR or cancel , then we will say the transfer function belong to FIR

- **Apply this filter to the ECG1 and then ECG2 signal?**

```
% Define the filter coefficients
a = [1, -1]; % Coefficients for the output HP(n)
b = [-1/32, zeros(1, 15), 1, -1, zeros(1, 14), 1/32]; % Coefficients for the
input X(n)

% Load your ECG signals (assuming they are stored in variables ECG1 and ECG2)
 ECG1 = A_ECG1;
 ECG2 = A_ECG2 ;

% Apply the filter to ECG1 and ECG2
filtered_ECG1 = filter(b, a, ECG1);
filtered_ECG2 = filter(b, a, ECG2);

% Plot the original and filtered ECG1 signals
figure;

plot(filtered_ECG1);
title(                      );

% Plot the original and filtered ECG2 signals
figure;

plot(filtered_ECG2);
title(                      );
```

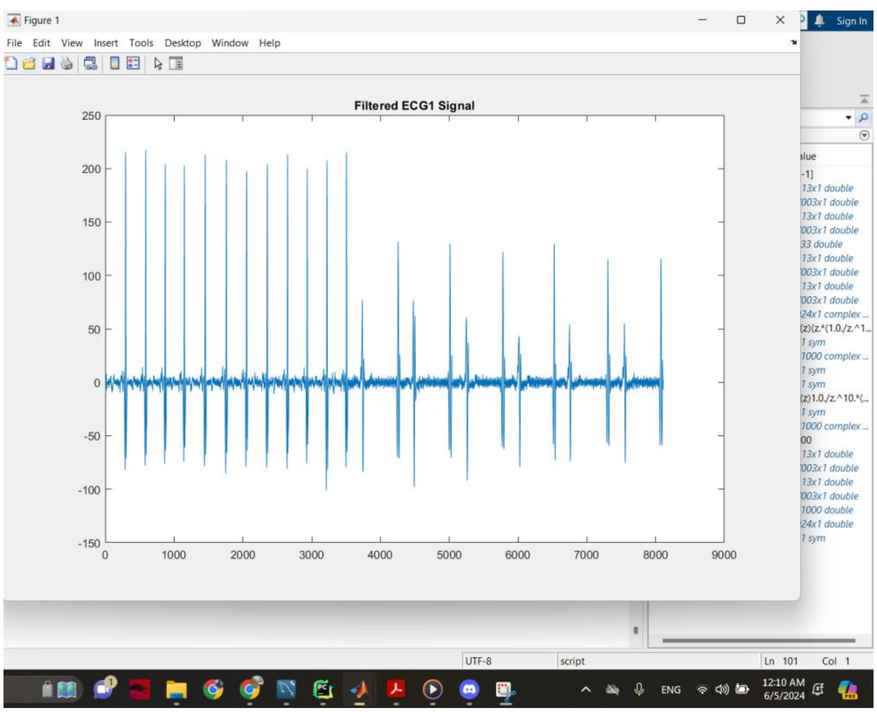

Figure 8 - Filtered ECG1 HP(n)

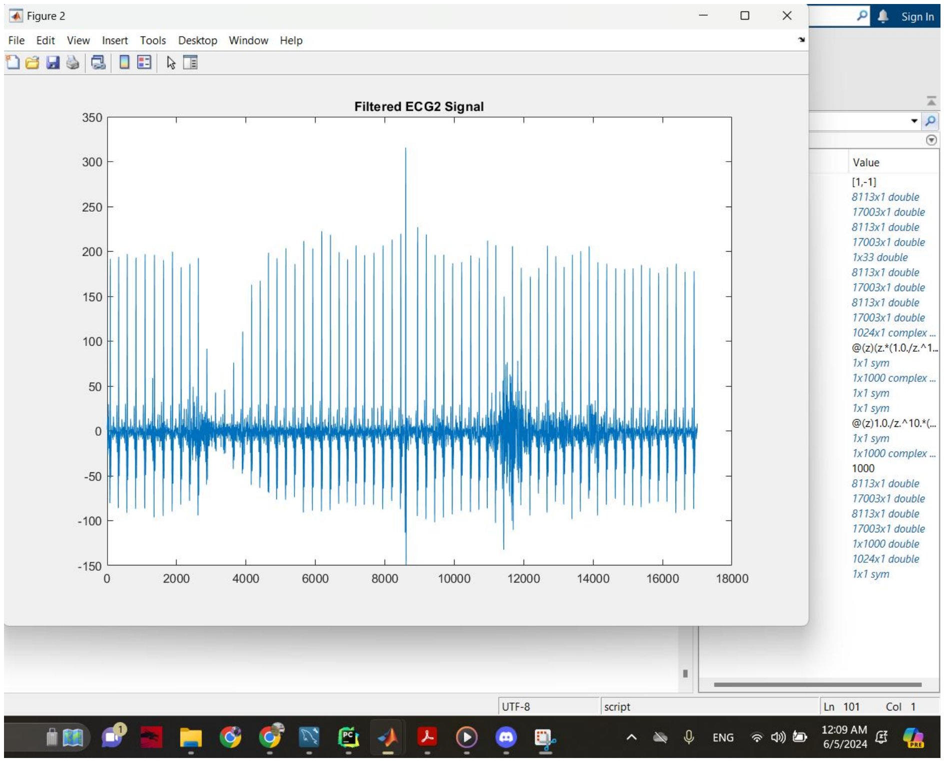

Figure 9 - Filtered ECG2 HP(n)

A. Filtered ECG1 Signal:

The filtered ECG1 signal shows a reduction in low-frequency components, making the high-frequency features of the ECG more visible. The plot indicates that the baseline wander has been effectively removed, resulting in a cleaner signal.

B. Filtered ECG2 Signal:

Similarly, the filtered ECG2 signal demonstrates a significant reduction in low-frequency noise. The high-pass filter has made the high-frequency details of the ECG2 signal more prominent, improving its readability and suitability for further analysis.

By applying the high-pass filter to the ECG1 and ECG2 signals, we have successfully attenuated the low-frequency noise, such as baseline wander, which typically obscures the important features of the ECG signals. The filtered signals are now more readable, allowing for easier identification of key ECG features. This step is crucial for accurate analysis and subsequent automatic processing of the ECG data.

- **How to partially resolve the problems occurring at the start of the signal?**

we can resolve the problems occurring at the start of the signal by concatenate the signals ECG1 and ECG2 with zeros :

we can conclude from above figures of ECG1 and ECG 2 signals there problem of noise in first 32 sample , where the filters cant solve it so we can solve it by concatenate the signals with zeros in first 32 sample and will be solved .

2.2 The low-pass filter:

LP (n) = 2.LP (n-1) - LP (n−2) + X (n) − 2X (n−6) + X (n−12)

- **Calculate its transfer function?**

$$LP(n) = 2\,LP(n-1) - LP(n-2) + X(n) - 2X(n-6) + X(n-12)$$

$$Z\{LP(n)\} = 2\,LP(z)\cdot z^{-1} - z^{-2}\,LP(z) + X(z) - 2X(z)\,z^{-6} + X(z)\,z^{-12}$$

$$LP(z) - 2LP(z)\cdot z^{-1} + z^{-2}\,LP(z) = X(z) - 2X(z)\,z^{-6} + X(z)\,X^{-12}$$

$$LP(z)\left(1 - 2\cdot z^{-1} + z^{-2}\right) = X(z)\left(1 - 2\cdot z^{-6} + z^{-12}\right)$$

$$\frac{LP(z)}{X(z)} = \frac{1 - 2z^{-6} + z^{-12}}{1 - 2z^{-1} + z^{-2}}$$

$$H(z) = \frac{1 - 2z^{-6} + z^{-12}}{1 - 2z^{-1} + z^{-2}}$$

Figure 10 - Transfer function LP(n)

- ## Find and plot the Frequency response?

```
%for the low pass filter

% Coefficients of the numerator
b1 = [1, 0, 0, 0, 0, 0, -2, 0, 0, 0, 0, 0, 1];

% Coefficients of the denominator
a1 = [1, -2, 1];

% Plot the frequency response
figure;
freqz(b1, a1, 1024);
title(                                        );
```

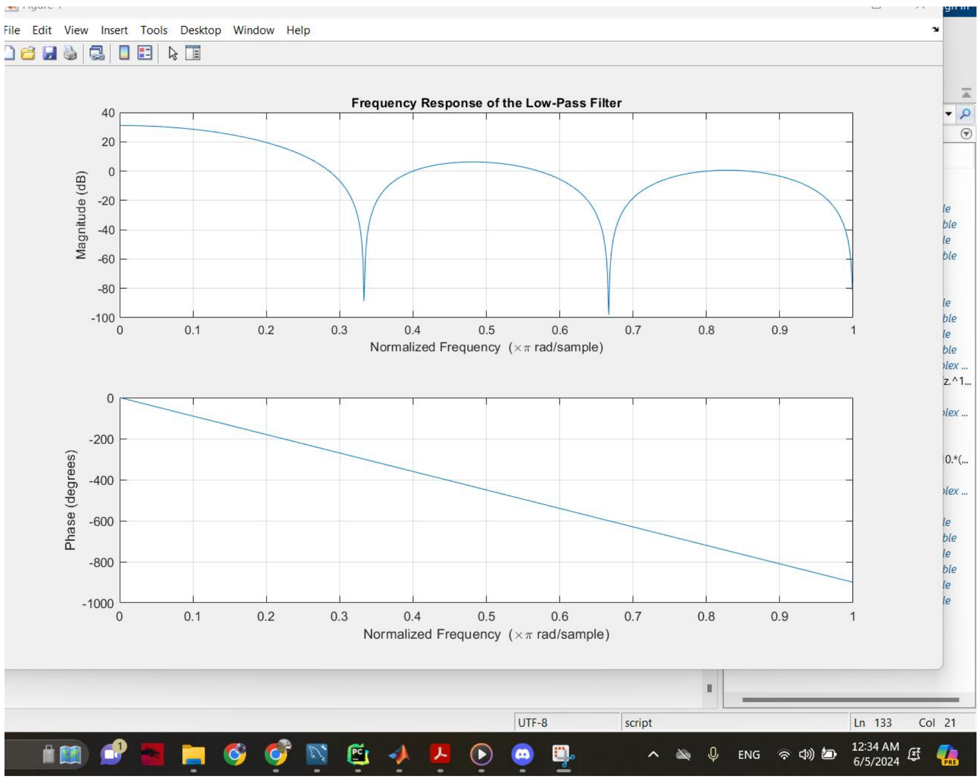

Figure 11 - Frequency response LP(n)

A. Magnitude Response:

The magnitude response plot shows how the amplitude of the output signal varies with frequency. For a low-pass filter, we expect the response to attenuate high frequencies and pass low frequencies. The plot indicates that the filter effectively reduces the amplitude of higher frequencies while allowing lower frequencies to pass through, confirming its low-pass characteristics.

B. Phase Response:

The phase response plot shows how the phase of the output signal varies with frequency. This is important for understanding the filter's effect on the phase of the input signal. The plot reveals a linear phase response, which is desirable for maintaining the waveform shape of the ECG signal after filtering.

The frequency response analysis confirms that the designed filter behaves as a low-pass filter, effectively attenuating high-frequency components and allowing low-frequency components to pass through. This behavior is consistent with the requirements for removing high-frequency noise from ECG signals. The plots provide a clear visualization of the filter's characteristics, supporting its suitability for the intended application of improving ECG signal readability and making them suitable for automatic processing.

- ## Which family does it belong to?

FIR , where we can see in the above transfer function for Low pass filter, in same way for HPF we have pole in zero point but the zero of transfer function in same place so will not be IIR or cancel , then we will say the transfer function belong to FIR on others poles

- ## Apply this filter to the ECG1 then the ECG2 signal?

```
%for the low pass filter
% Load your ECG signals (assuming they are stored in variables ECG1 and ECG2)
 ECG1 = A_ECG1;
 ECG2 = A_ECG2 ;

% Coefficients of the numerator
b1 = [1, 0, 0, 0, 0, 0, -2, 0, 0, 0, 0, 0, 1];

% Coefficients of the denominator
a1 = [1, -2, 1];

% Apply the filter to ECG1 and ECG2
filteredLP_ECG1 = filter(b1, a1, ECG1);
filteredLP_ECG2 = filter(b1, a1, ECG2);

% Plot the original and filtered ECG1 signals
figure;

plot(filteredLP_ECG1);
title(                                          );

% Plot the original and filtered ECG2 signals
figure;
plot(filteredLP_ECG2);
title(                                         );
```

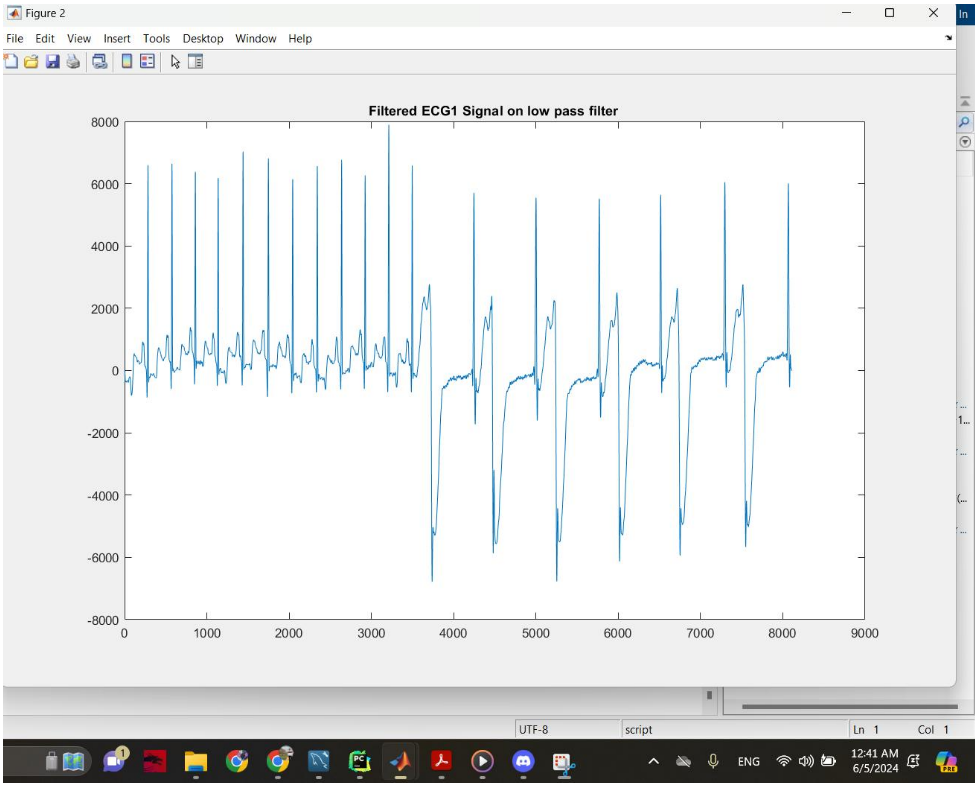

Figure 12 - Filtered ECG1 LP(n)

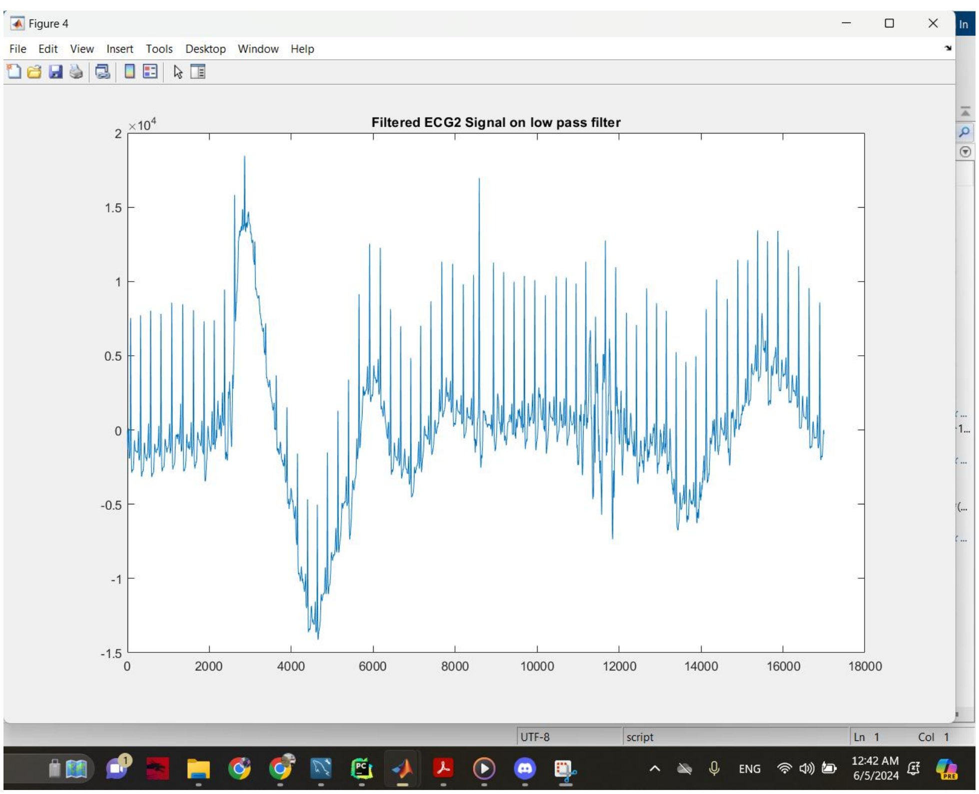

Figure 13 - Filtered ECG2 LP(n)

A. Filtered ECG1 Signal:

The filtered ECG1 signal shows a reduction in high-frequency components, making the low-frequency features of the ECG more visible. The plot indicates that the high-frequency noise has been effectively removed, resulting in a cleaner signal.

B. Filtered ECG2 Signal:

Similarly, the filtered ECG2 signal demonstrates a significant reduction in high-frequency noise. The low-pass filter has made the low-frequency details of the ECG2 signal more prominent, improving its readability and suitability for further analysis.

By applying the low-pass filter to the ECG1 and ECG2 signals, we have successfully attenuated the high-frequency noise, which typically obscures the important features of the ECG signals. The filtered signals are now more readable, allowing for easier identification of key ECG features. This step is crucial for accurate analysis and subsequent automatic processing of the ECG data.

2.3 Use the output of the high pass filter as the input of the low pass filter and display the result obtained for ECG1 and ECG2. Is there a difference if you reverse the filters?

```
% Define the filter coefficients
a = [1, -1]; % Coefficients for the output HP(n)
b = [-1/32, zeros(1, 15), 1, -1, zeros(1, 14), 1/32]; % Coefficients for the
input X(n)

% Load your ECG signals (assuming they are stored in variables ECG1 and ECG2)
 ECG1 = A_ECG1;
 ECG2 = A_ECG2 ;

% Apply the filter to ECG1 and ECG2
filtered_ECG1 = filter(b, a, ECG1);
filtered_ECG2 = filter(b, a, ECG2);

%for the low pass filter

% Coefficients of the numerator
b1 = [1, 0, 0, 0, 0, 0, -2, 0, 0, 0, 0, 0, 1];

% Coefficients of the denominator
a1 = [1, -2, 1];

% Apply the filter to ECG1 and ECG2
filteredLP_ECG1 = filter(b1, a1, ECG1);
filteredLP_ECG2 = filter(b1, a1, ECG2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% pass the signal to low pass after pass it
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% to high pass

% Apply the filter to ECG1 and ECG2
filteredDONE_ECG1 = filter(b1, a1, filtered_ECG1);
filteredDONE_ECG2 = filter(b1, a1, filtered_ECG2);

% Plot the original and filtered ECG1 signals
figure;

plot(filteredDONE_ECG1);
title(                           );

% Plot the original and filtered ECG2 signals
figure;
plot(filteredDONE_ECG2);
title(                           );
```

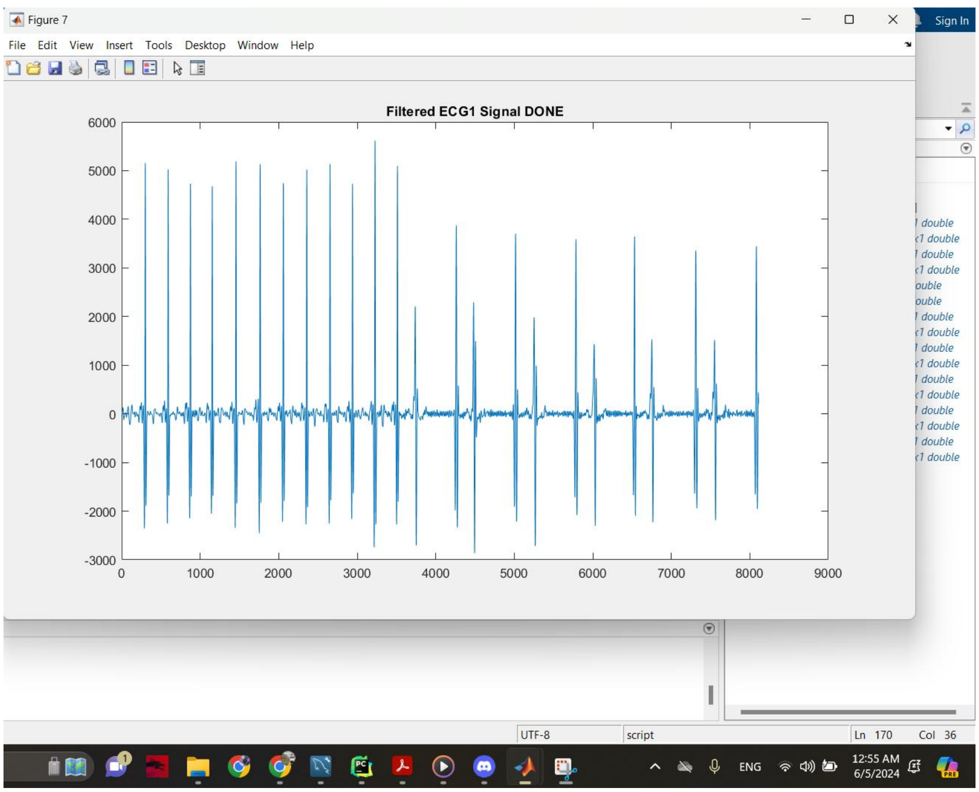

Figure 14 - Filtered ECG1 Done

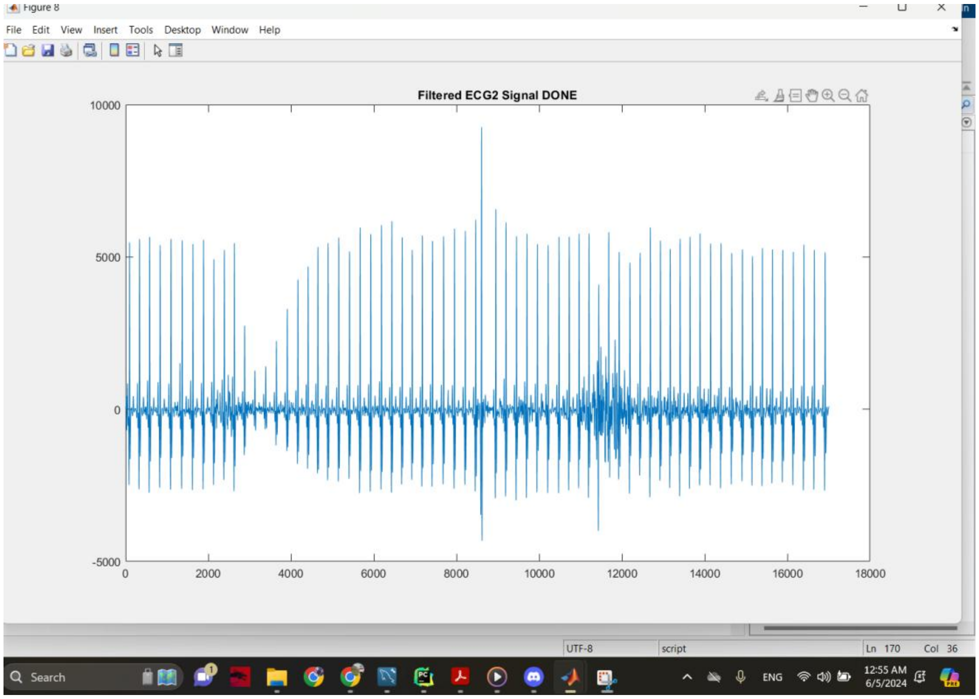

Figure 15 - Filtered ECG2 Done

In this part we entered data on High pass filter and the output of this filter then we entered it again into Low pass filter, and then we plot it.

Conclusion

In conclusion, this project demonstrates the application of digital signal processing techniques to real electrocardiographic signals. Through the use of high-pass and low-pass filters, the clarity and readability of the ECG data were significantly enhanced, facilitating more accurate peak detection and classification.