David Cracknell
reg No: 220139519
EEE339 Digital signal processing 2024/25

Semester 2 Coursework Report: Heart rate filtering

1. Project introduction

1.1 Requirements

The project requirement is to design two 5th-order digital filters (FIR and IIR) to remove noise from a noisy electrocardiogram (ECG) signal of a patient with a heart condition. For this coursework, ECG Data 1 was selected, representing a 69-year-old male exhibiting premature ventricular contraction (PVC).

The provided ECG signals, sampled at 360 Hz, include both an original signal and a noisy version. Each signal spans a duration of ten seconds, with voltage measured in millivolts (mV).

This report covers the process of designing these filters in MATLAB, including analysis of signal characteristics, frequency domain examination using FFT, selection of an appropriate cutoff frequency to eliminate noise (particularly high-frequency interference and mains hum), and comparative evaluation of the FIR and IIR filter performances.

1.2 Unfiltered heartbeat

Figure 1 below compares the noisy ECG signal with the original ECG signal. To calculate the patient's heart rate, the time interval between the first and tenth heartbeat peaks is measured. Since this interval contains 9 full beats, the number of beats is taken as 9. The heart rate (in beats per minute, bpm) was then calculated using the formula:

$$HeartRate(bpm) = \frac{\text{Number of beats}}{\text{Time interval (seconds)}} \times 60 \quad (1)$$

Substituting the measured values into this formula gave a heart rate of approximately 83.4 bpm.

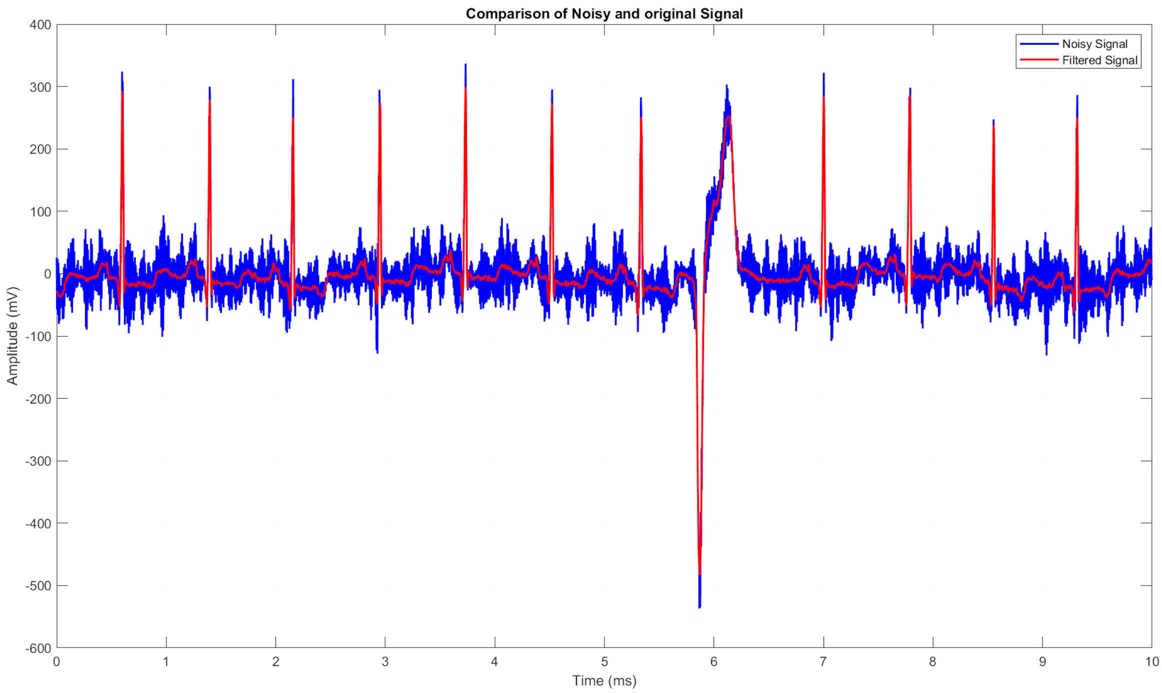


Figure. 1 Graph of the unfiltered noisy signal and the original signal

2. Fourier Transform and filtering

2.1 Fourier Transform of the noisy signal

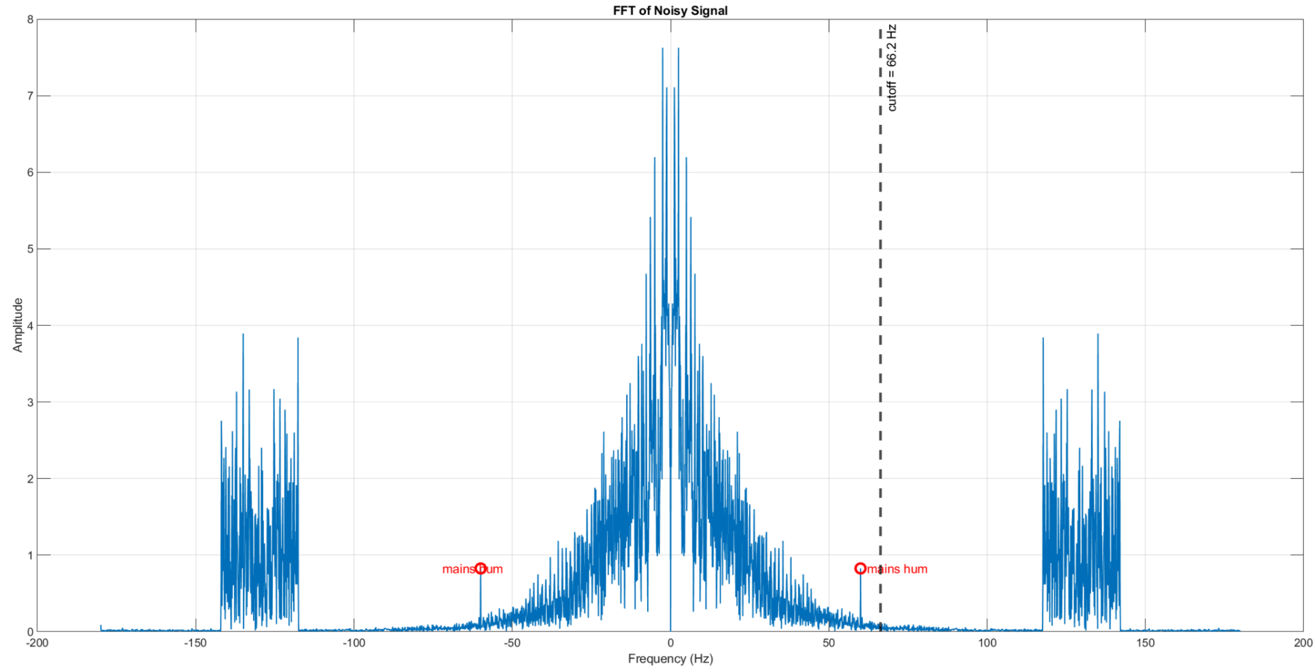


Figure 2. Graph of the Fourier transform of the noisy signal with mains hum and cut-off frequency

Looking at Figure 2, you can see a minor peak marked by red circles at 60 Hz, indicating interference from mains electricity (mains hum). This suggests the geographical origin of the data, as countries using a 60 Hz electrical supply are predominantly located in North and South America.

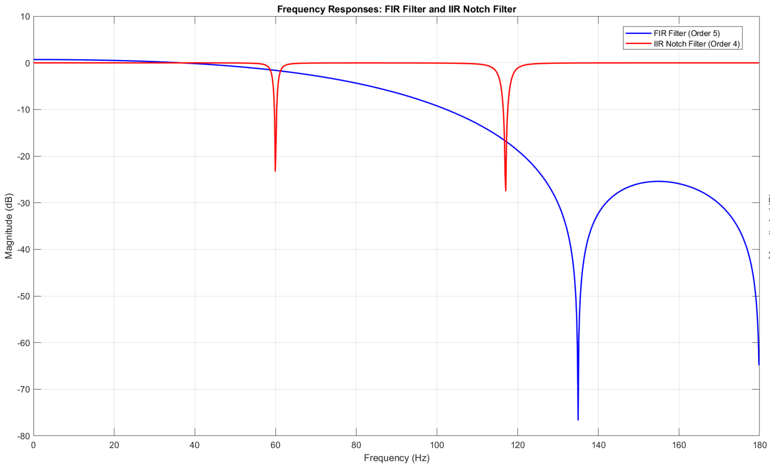
2.2 Filter design

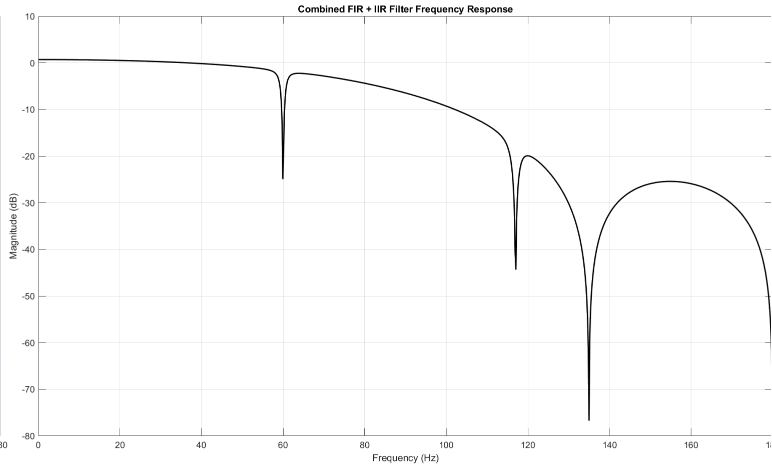
Most of the ECG signal energy in Figure 1 is concentrated in the lower frequency range, implying that the required filtering must prioritise preserving these lower-frequency components. Figure 1 shows that the vast majority of the noise is after the 117Hz point of the graph, so removing this is the main aim of the FIR.

After performing several trial-and-error iterations using MATLAB's DSP tools, a cut-off frequency of 66.2 Hz (which translates to a normalised frequency is approximately 0.184 cycles per sample) was deemed to be the ideal cut-off for the FIR filter considering the limitation to using 5th-order filter, which is the highest order allowed by the assignment constraints. This particular high cut-off frequency was chosen to maintain the essential features of the ECG waveform while attenuating at the high frequencies, allowing for a high signal-to-noise ratio.

$$\text{Normalised Frequency} = \frac{\text{Cutoff Frequency}}{\text{Sampling Frequency}} = \frac{66.2\,\text{Hz}}{360\,\text{Hz}} = 0.184\,\text{cycles/sample} \quad (2)$$

Using the Infinite Impulse Response (IIR) filter allows for precise targeting and removal of specific unwanted frequencies, particularly the 60 Hz mains interference. A 4th-order IIR filter was chosen as this particular order effectively reduced the interference from the 60 Hz mains frequency and also allowed for additional blocking of the next prominent noise peak at around 117 Hz. Targeting these frequencies allows for removing spiked frequencies from another source while having a minimal effect on the signal itself.





Figures 3 & 4 Graphs of the separated IIR &FIR frequency response and a graph of the combined IIR and Fir frequency response

2.2 Fourier Transform of the filtered signal

Figure 5 is the graph after being filtered. Most of the noise has been removed, with a few small lumps with a max amplitude of about 0.3 remaining. This design achieved this while maintaining the majority of the original signal and removing all noise at 60 and 117Hz effectively, allowing for a high signal-to-noise ratio.

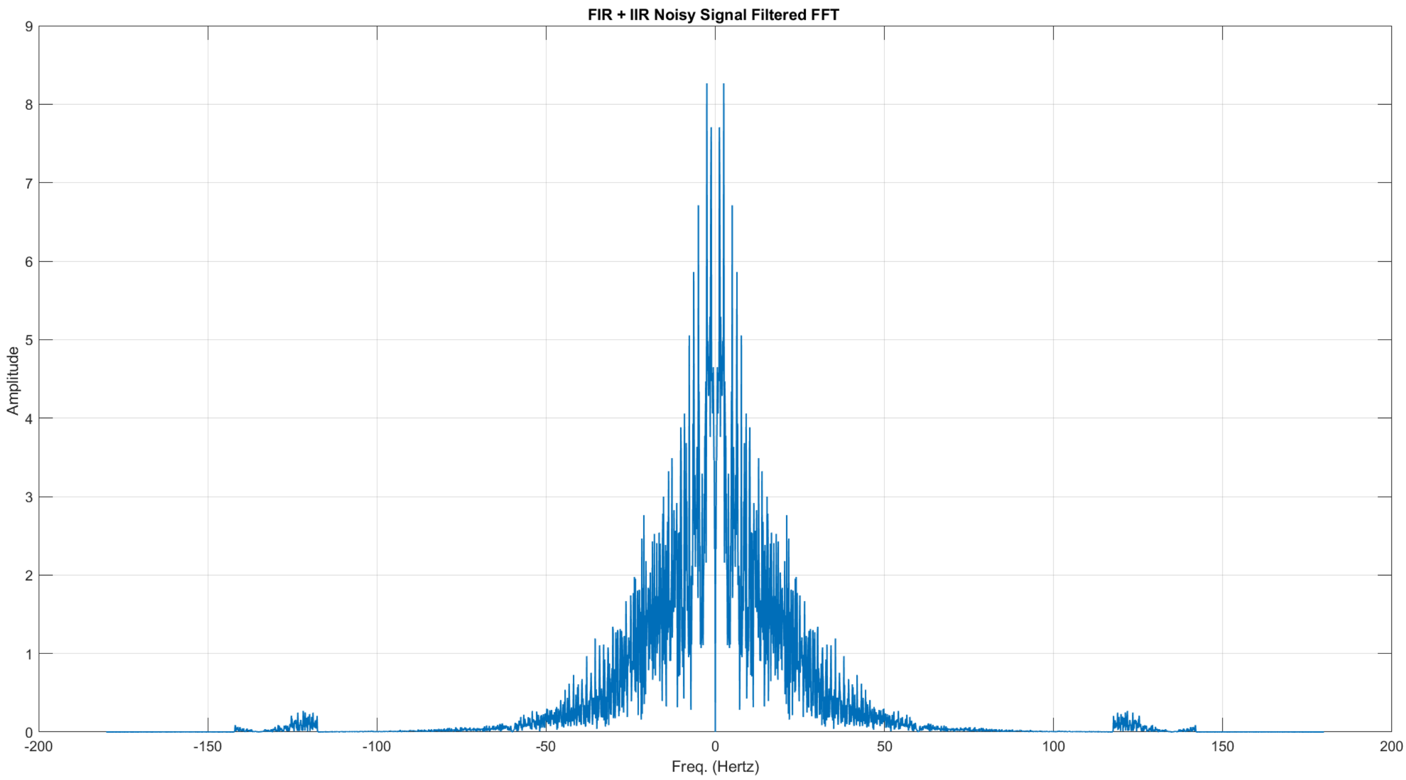


Figure 5. Post-filtering FFT graph of noisy signal
Change title to amplitude of freq

3. Filtered Signal vs. Original Signal

Figure 6 shows the combined plot of the filtered signals compared with the original signal. Compared with Figure 1, there is a huge improvement in signal readability after the filtering. This allows us to have a detailed view of the central segment of the heartbeat, clearly showing the full PQRST wave, which can provide critical diagnostic info on a patient's heart health.

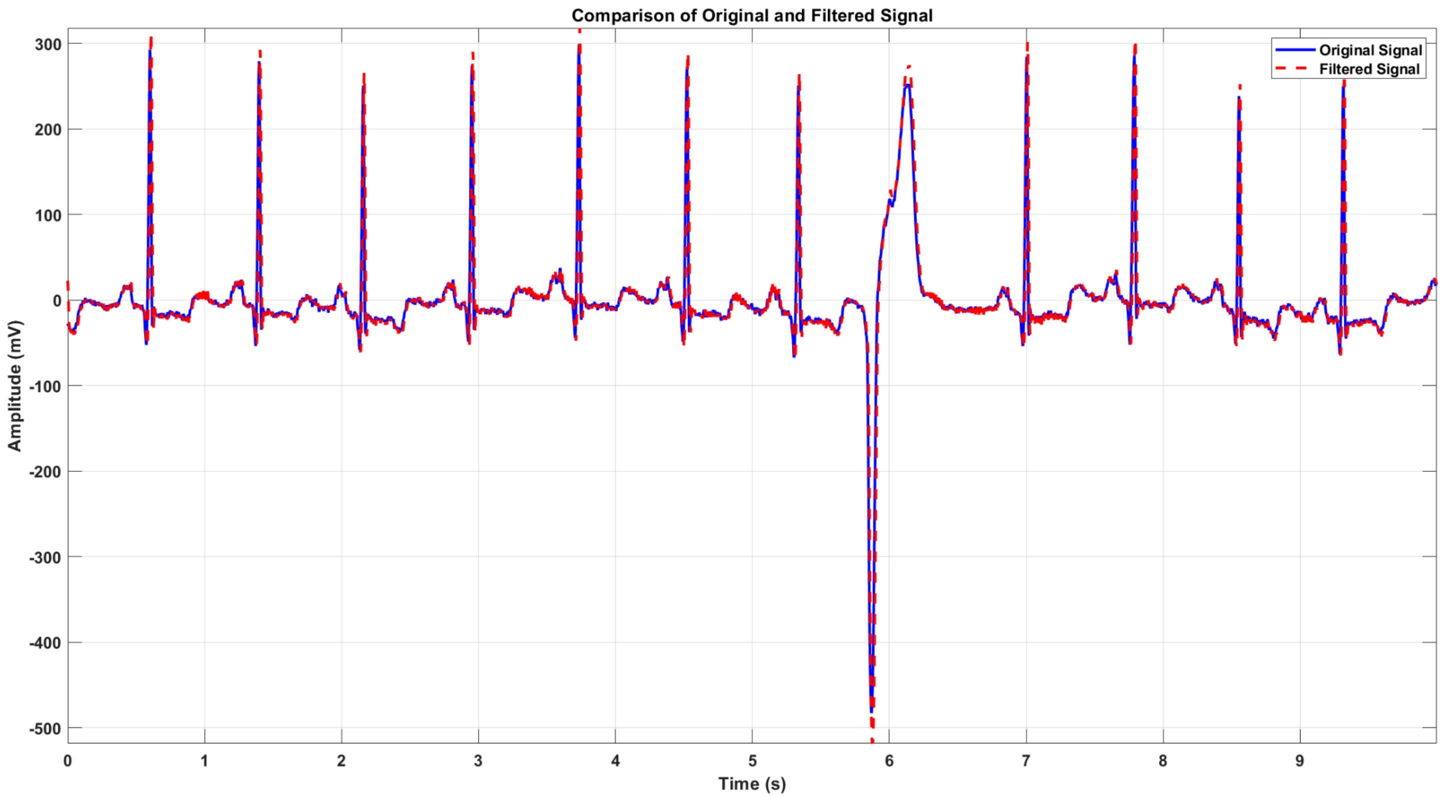


Figure 6. Full Graph of the original signal compared to the filter noisy signal signal

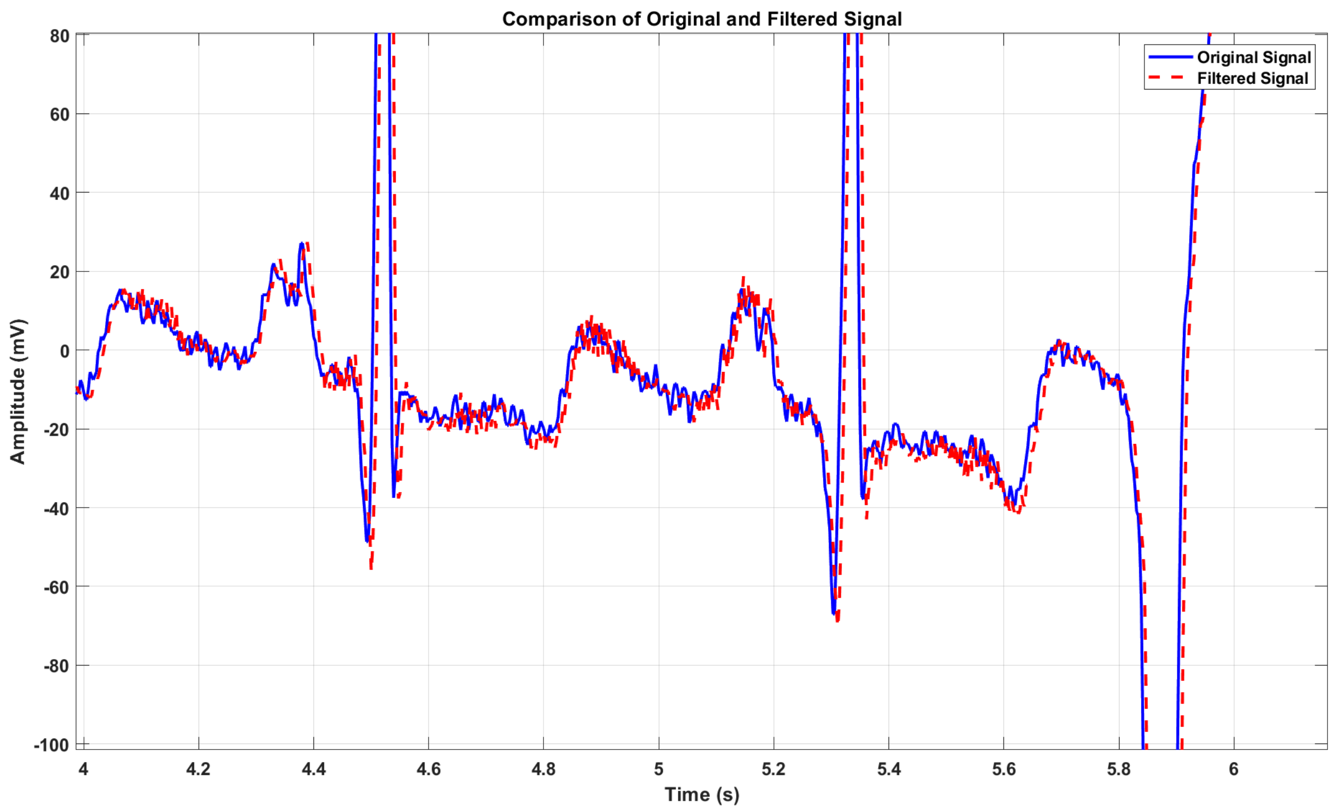


Figure 7. Zoomed-in graph of the original signal to filter signal

4. Potential Improvements

The residual noise peak at 117 Hz is a noticeable problem when examining the post-filter FFT graph. Adaptive filtering methods, such as the Least Mean Squares (LMS) algorithm, would be a helpful improvement. This algorithm continuously modifies its filter coefficients in real time in response to variations between the intended and actual output. It effectively "learns" the ideal filter response as the signal conditions change by minimising the mean square error through a feedback mechanism.

LMS filtering is particularly well-suited for ECG signals because its versatility allows it to adapt to noise characteristics that change over time. The LMS filter can significantly reduce residual noise without changing the underlying ECG waveform by automatically adjusting itself to suppress varying interference, such as the 117 Hz component. This results in a cleaner frequency spectrum, which is shown as a smoother FFT graph with the unwanted peaks reduced and increased the signal's diagnostic value by preserving critical morphological features.

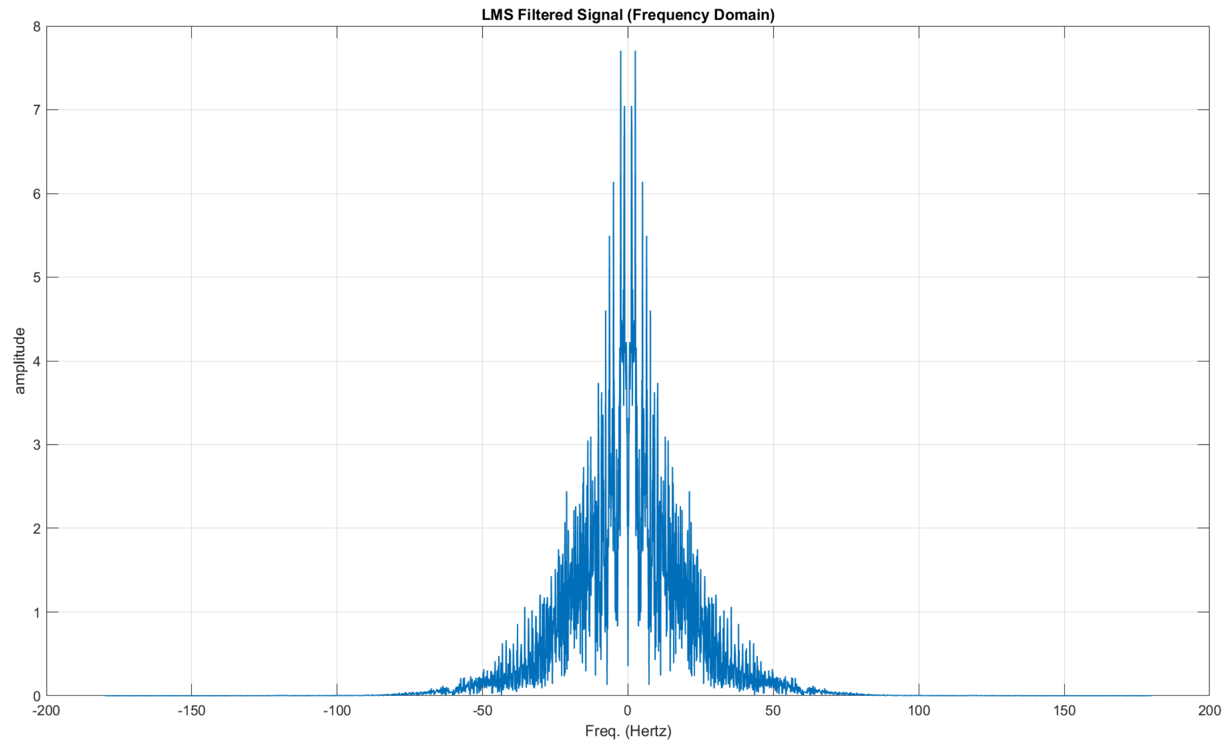


Figure 8. FFt graph of improved LMS filtered signal

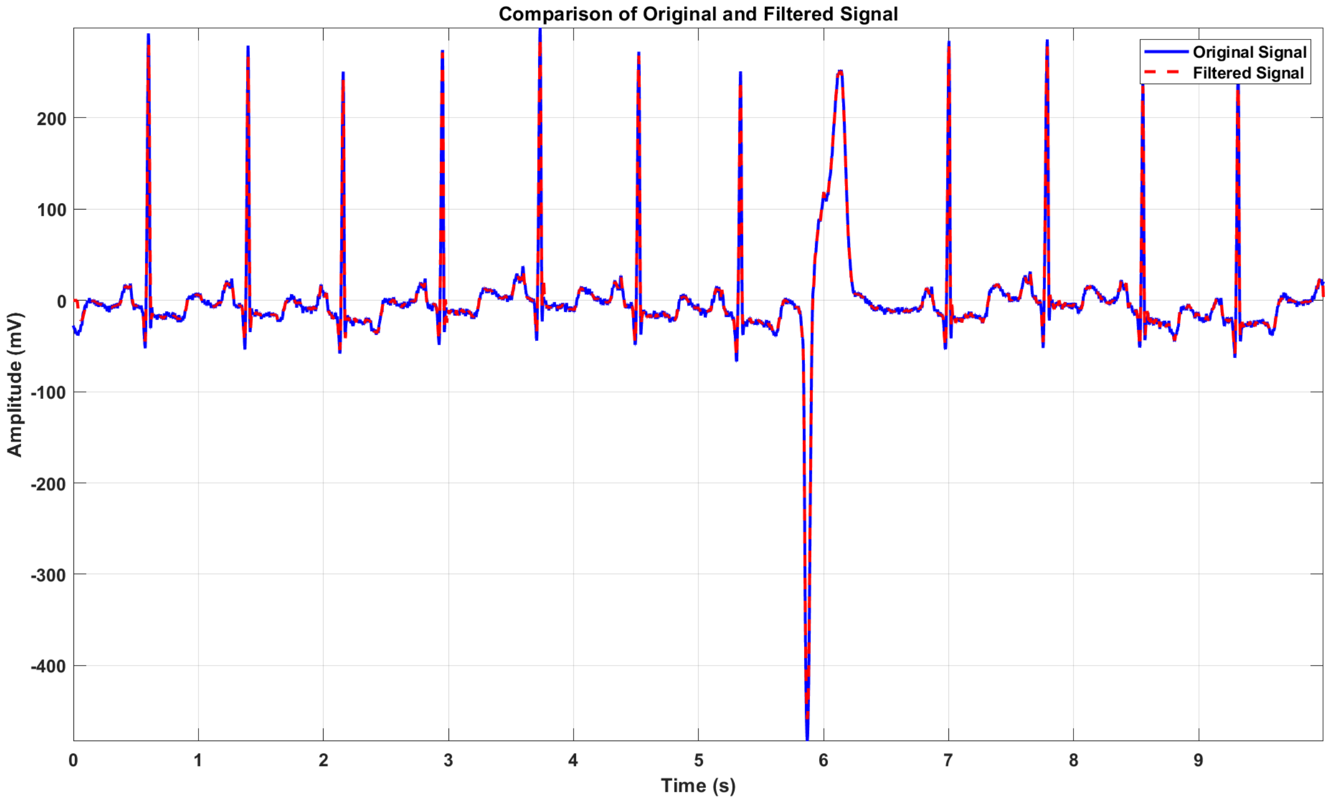


Figure 9. Graph of improved LMS-filtered signal compared to the original signal

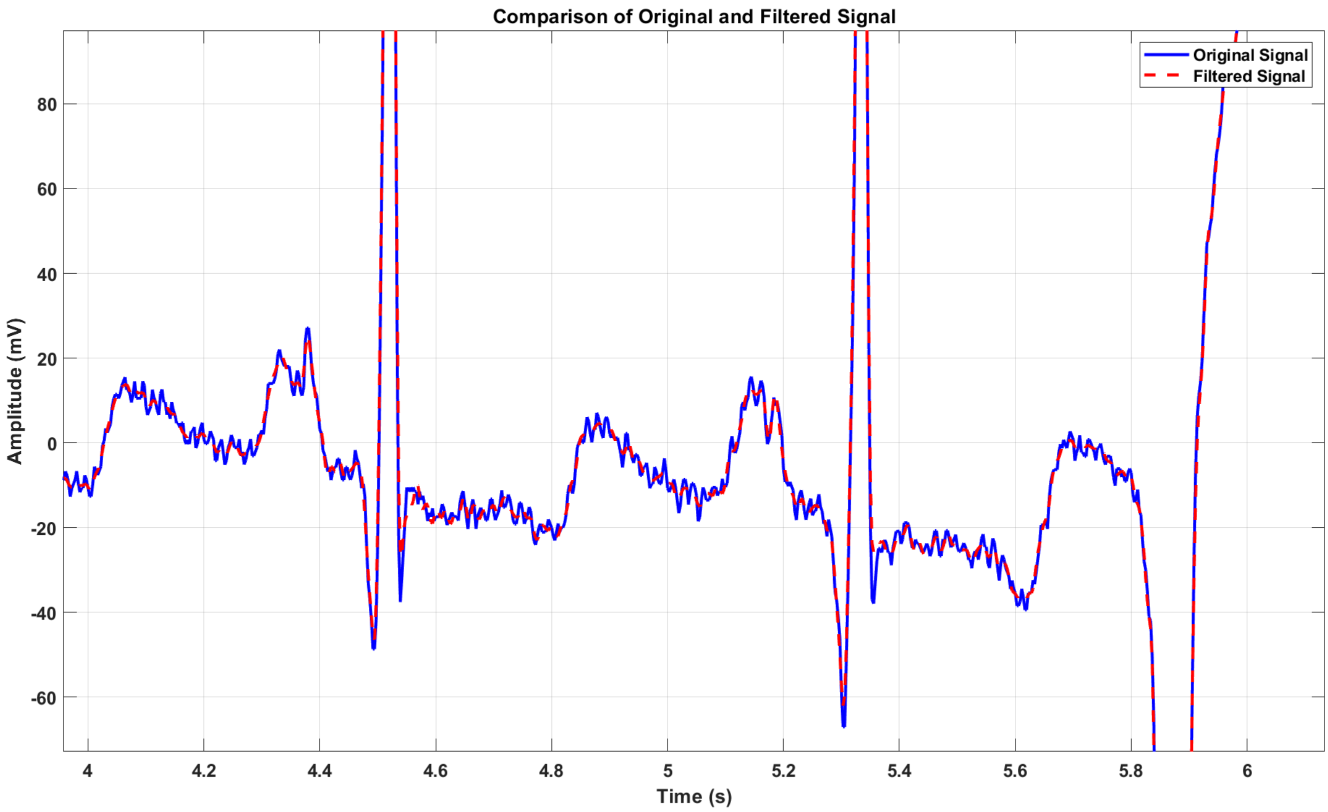


Figure 10. Zoomed-in graph of improved LMS-filtered signal compared to the original signal