Digital Filters for Removal of Baseline Wanders (less than 0.7 Hz) and 50 Hz Powerline Interference

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***Abstract*— This paper presents the design of digital filters for removing baseline wanders and 50 Hz powerline interference from EEG signals. Low frequency variation in biological signals is called baseline wanders. Powerline interference occur due to the coupling of powerline frequencies to the device used to read the signals. These unwanted interferences to our readings can be removed using filters designed specifically for this purpose**

Keywords—baseline wanders, powerline interference

I. Introduction

Electrocardiography is a method of producing a record of the heart's electrical activity, called an electrocardiogram (ECG or EKG). This involves placing electrodes on the skin to detect the electrical changes that occur during each heartbeat as the heart muscles depolarize and repolarize. Abnormalities in the ECG pattern can indicate various cardiac conditions, including irregular heart rhythms, insufficient blood flow to the heart muscle, and imbalances in electrolyte levels[1]. Powerline interference is the noise caused due to power supply to the ECG machine. They will be at the same frequency as the AC power supply frequency and in harmonics of this frequency. These can be removed using a second order band stop filter with the notch frequency as 50 Hz. Baseline wander is a low-frequency artefact in electrocardiogram (ECG) signal recordings. These can be removed by using a first order high pass filter with cut-off frequency of 0.7 Hz. Another method to perform these functions is to set the Discrete Fourier Transform (DFT) coefficients of the frequencies to be removed as zero in the DFT of the corrupted signal and then taking the inverse DFT to obtain the filtered signal. In this project we will be designing digital filters specifically for removing baseline wanders and powerline interference from an ECG signal. This must be done as the further use of ECG requires the ECG to be without unwanted noise.

A. *Major Contibution*

- Calculating the transfer function of band-stop filter for removing powerline interference.
- Calculating the transfer functions of high-pass filter for removing baseline wanders with frequency less than 0.7Hz.
- Improving the quality of biological signals like ECG for further analysis.

B. *Organization of the Paper*

Materials and Methods consists of the calculation of transfer functions of the filters that we use. It consists of the design formulas and pole zero placements in order to obtain the required output.

Proposed method consists of the use of these filters to remove the unwanted noises rom our ECG signal.

Pseudo Code consists of how the code is arranges and how it works.

Performance metrics and Database consists of how the database was procured and how the code works with different databases.

Results section consists of the results of the project from the code and plots used to confirm and visualise the proper working of the code.

Conclusions mentions the important inferences from this project.

II. Materials and METHODS

A. *Concepts of DFT*

Second-order Bandstop Filter Design

Poles are complex conjugate, with the magnitude r controlling the bandwidth and the angle is controlling the center frequency. The zeros are placed on the unit circle with the same angles with respect to the poles. This will improve passband performance. The magnitude and the angle of the complex conjugate poles determine the 3 dB bandwidth and the center frequency, respectively [2].

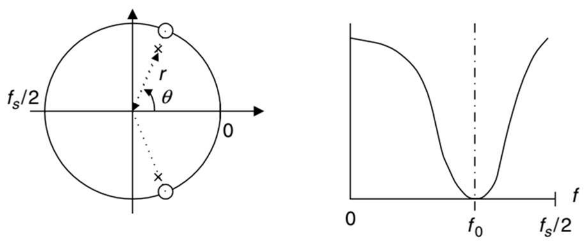


Fig1: Pole-zero placement for notch filter

Design formulas [2]:

Distance of poles from the origin:

$$r \approx 1-(BW_{3dB} / F_s) \qquad (1)$$

where F_s is the sampling frequency of the ECG signal and BW_{3dB} is the bandwidth of the filter.

Angle of complex conjugate poles and zeros,

$$\Theta = (f / F_s) \times 360^0 \qquad (2)$$

Where f is the notch frequency of the band-stop filter.

Transfer function of the filter is given by:

$$H(z) = \frac{K(z-e^{j\theta})(z+e^{-j\theta})}{(z-re^{j\theta})(z-re^{-j\theta})} = \frac{K(z^2-2z\cos\theta+1)}{(z^2-2rz\cos\theta+r^2)}. \qquad (3)$$

Where K is given by

$$K = \frac{(1 - 2r\cos\theta + r^2)}{(2 - 2\cos\theta)}. \qquad (4)$$

K is the scale factor to adjust the band stop filter to have a unit passband gain.
The calculated values are:
r = 0.95
$\Theta = 18^0$

First-order high pass filter design

The pole z = α is placed in the real axis. The zero is placed at z = 1 to ensure zero gain at the folding frequency (Nyquist limit).

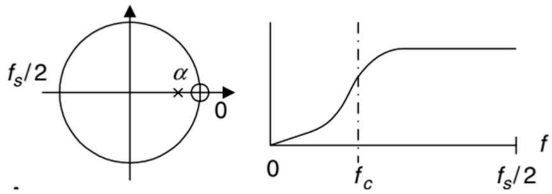


Fig 2: Pole-zero placement for high pass filter

Design Formulas [2]:

When $f_c < F_s / 4$, $\alpha \approx 1 - 2\Pi (f_c / F_s)$, $0.9 \leq r < 1$ (5)

Where f_c is the cutoff frequency of the filter and r is the distance of the pole from the origin.

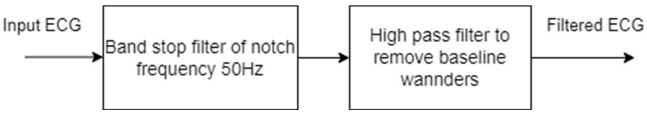
Transfer function of high pass filter:

$$H(z) = \frac{K(z-1)}{(z-\alpha)} \qquad (6)$$

Where K is given by,

$$K = \frac{(1+\alpha)}{2}. \qquad (7)$$

B. Proposed Method



The input ECG is corrupted due to powerline interference and baseline wanders. The input signal is passed through a band stop filter with notch frequency as the frequency of the AC power signal is of 50 Hz. The transfer function calculated using the equations (3) and (4) is:

$$H(z) = \frac{0.97553966z^{-2} - 1.8555867z^{-1} + 0.97553966}{1 - 1.80700738z^{-1} + 0.9025z^{-2}}$$

K = 0.97553966

After filtering through the band stop filter, the signal is then passed through a high pass filter with cutoff frequency 0.7Hz to remove the baseline wanders. Transfer function calculated using (6) and (7) is:

$$H(z) = \frac{0.99780089 - 0.99780089z^{-1}}{1 - 0.99560177z^{-1}}$$

K = 0.99780089

The output after these two steps will be filtered ECG signal which can be used for further assessment of a patient's health condition.

C. Pseudo Code

Step 1: Reading the CSV file with corrupted ECG and setting the time and sampling rate according to the CSV file.
Step 2: Displaying the corrupted signal and its DFT after calculating the corrupted signal's DFT. Peaks in DFT can be observed at 50Hz and at low frequencies.
Step 3: Calculation of coefficients of different exponents of z in the transfer function using equation (3) for removing powerline interference and applying the filter on the signal.
Step 4: Calculating and displaying the DFT. The 50Hz component that was present can be observed to be very low in magnitude now.
Step 5: Calculation of coefficients of different exponents of z in the transfer function using equation (6) for removing baseline wanders and applying the filter on the signal.
Step 6: Calculating and displaying the DFT. The low frequency components that were present in the DFT can be observed to be very low in magnitude now.
Step 7: Displaying the final filtered signal without unwanted frequencies.
Step 8: Displaying graphs in the GUI

D. Performance Metrics and Database

The bandwidth of the band stop filter changes with the value of 'r' that we have used. The database used for procuring the ECG is given here. The ECG used is of 1.2 seconds and is sampled at a sampling rate of 1000 samples per second. The given database (CSV file) contains multiple ECG signals under different column names. Changing the column to be read in the code will change the signal to be filtered. The filers have been confirmed to work on all the columns in the given dataset. Using another database may require to modify the code according to the sampling rate and duration of the signal according to the database.

III. Results Section

A. Figures and Tables

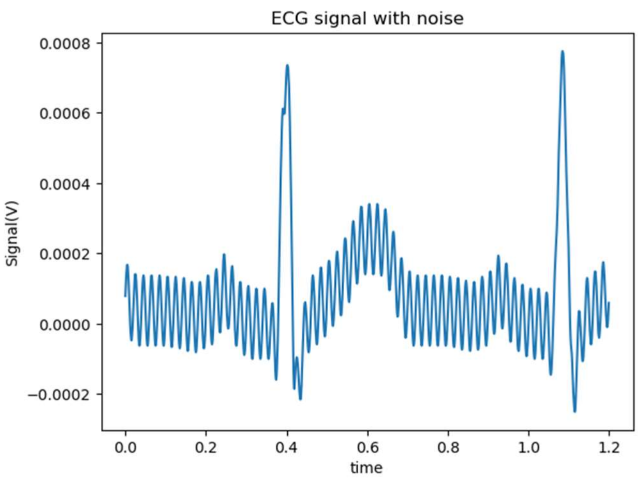


Fig3: Corrupted ECG signal

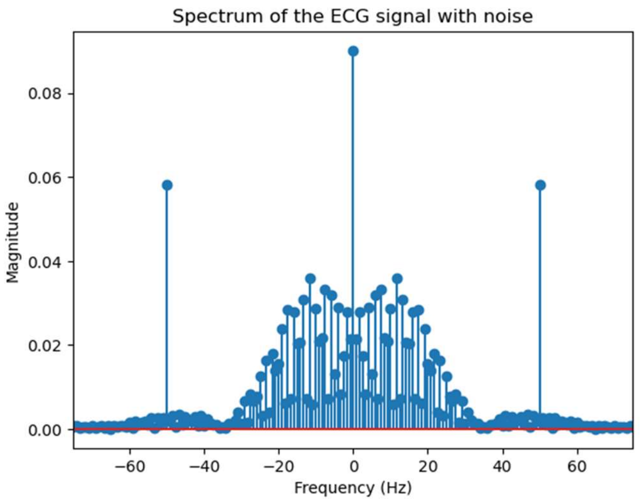


Fig 4: Frequency Spectrum of the corrupted ECG

High magnitude of DFT at low frequencies and 50Hz can be seen.

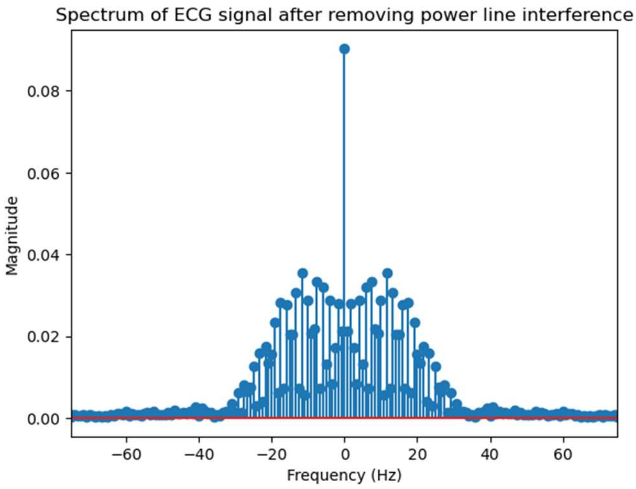


Fig 5: Frequency Spectrum after passing through 50Hz notch filter

50Hz component in the DFT is of very low magnitude now.

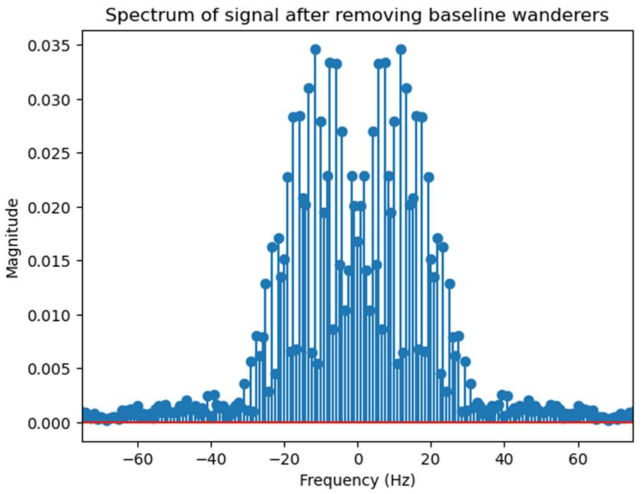


Fig 6: Frequency spectrum after passing through high pass filter

Low frequency component in the DFT is of very low magnitude now.

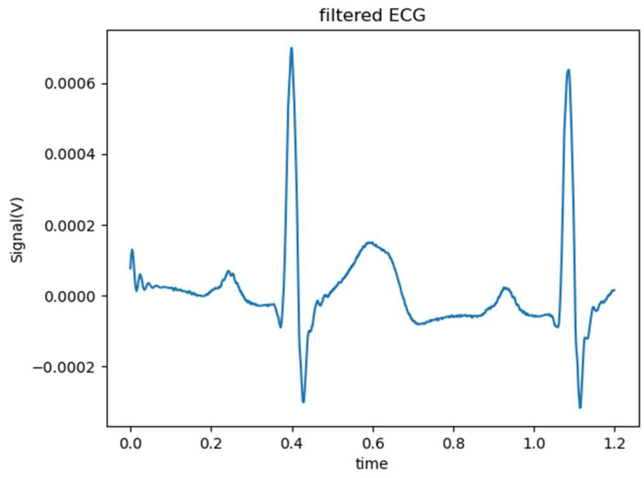


Fig 7: Final filtered ECG

IV. CONCLUSIONS

- The use of a band stop filter to remove powerline interference and a high pass filter to remove baseline wanders proved to be an effective approach in improving the quality of biological signals.
- The results of this project demonstrate that the proposed filters were able to effectively remove unwanted signals without significantly distorting the desired signal.
- The pole-zero placements of the filters can alter the results by changing the filtering frequencies and also the bandwidth.
- Results of this project suggest that the use of appropriate digital filters can greatly enhance the reliability and accuracy of biological signal analysis, particularly in settings where noise and interference are common issues.

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REFERENCES

[1] "15.3.1 Electrocardiographic Terms",AMA Manual of Style, American Medical Association.

[2] Li Tan, "Digital Signal Processing Fundamentals and Applications"