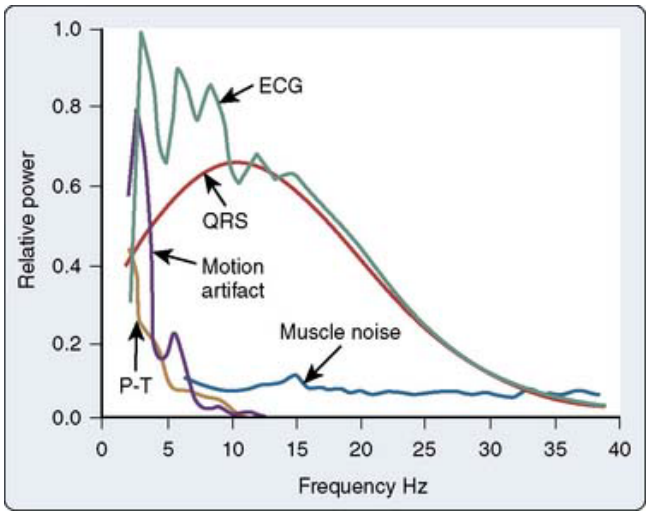
Homework #4

2022 EE401
Digital Signal Processing

The heart beats in synchronization with electrical signal initially generated by the sinus node that is called the natural pacemaker. An electrocardiogram (ECG) records the electrical signal from the heart and consists of three distinctly shaped waves: P wave, QRS complex, and T wave (see page 20 of Lecture Note #1). Abnormal shape of these waves is associated with heart diseases such as ischemic heart disease and atrioventricular (AV) block. Also, the spectrum of each wave has a unique shape, and heart diseases cause changes in the shape of the spectrum. The following figure shows the spectrum of the waves from a normal heart.



The ECG1.mat file contains data recorded from a normal ECG. You can read the data on MATLAB by typing `load("ECG1.mat")`. By doing so, the variable ECG1 containing the data is automatically generated. The sampling interval of the data is 8 ms.

1. (60 pts) Spectral analysis
   a) Write a MATLAB program to obtain the spectrum of the ECG signal. Plot the ECG signal and its magnitude spectrum. For the ECG signal, the x-axis should be time and the y-axis should be the amplitude of voltage. For the spectrum, the x-axis should be frequency and the y-axis should be normalized magnitude in dB. (40 pts)
   b) The original ECG signal contains artifacts and noise. Explain the characteristics of the unwanted signals in time and frequency domains and relationship between these characteristics. (20 pts)

2. (130 pts) Window-based FIR Filter Design
   a) The frequencies higher than 4 Hz has important information about the ECG signal, and those lower than 1 Hz contain the artifacts. Determine the passband and stopband frequencies and the filter cutoff frequency based on the result of the Question #1. (10 pts)
   b) Stopband attenuation should be less than 40 dB. Select a suitable window and determine the minimum filter length to meet the requirements. (20 pts)

c) Design a filter to remove the artifacts on MATLAB. You may use the fir1() function. Plot the impulse response of the filter, the magnitude and phase of the filter transfer function as a function of frequency. (50 pts)
d) Conduct filtering with the designed filter. Plot the filtered ECG signal and its magnitude spectrum. (50 pts)

3. (130 pts) IIR Butterworth Filter Design
   a) By using MATLAB functions, i.e., buttord(), butter() functions, obtain the coefficients of the transfer function. Show the magnitude and phase of the filter transfer function as a function of frequency, and pole-zero plot. (50 pts)
   b) Plot the phase delay and group delay of this filter as a function of frequency. (30 pts)
   c) Conduct filtering with the designed filter. Plot the filtered ECG signal and its magnitude spectrum. (50 pts)

4. (70 pts) Evaluation
   a) Are the ECG signals filtered by the FIR and IIR filters identical to each other? If not, explain why two ECG signals are different. (20 pts)
   b) Plot the power spectral density of the two filtered ECG signals. You may use pwelch() function provided by MATLAB. (30 pts)
   c) Based on all of the results that you have obtained, discuss the advantages and disadvantages of FIR and IIR filters. (20 pts)