EE 274 / CoE 197E IIR Filter Design

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Instructions: You are to submit a pdf document containing the answers to the questions in this exercise. Submit your pdf together with the m-files as a zip file and submit via UVLe before the deadline.

IIR Filters

1. **Analog Filter Design**. An *analog* lowpass filter is to be designed that requires the following specifications:

   $0.99 \le |H(w)| \le 1$ for $0 \le f \le 1500$Hz
   $0 \le |H(w)| \le 0.01$ for $f \ge 2000$Hz

   a) What is the lowest-order Butterworth filter that satisfies the specifications? Show the magnitude response of your filter, and that the filter satisfies the specs. Note: Using butter() with 's' option will design an analog filter.
   b) What is the lowest-order Chebyshev Type I filter that satisfies the specifications? Show the magnitude response of your filter, and that the filter satisfies the specs.
   c) What is the lowest-order Chebyshev Type II filter that satisfies the specifications? Show the magnitude response of your filter, and that the filter satisfies the specs.
   d) Compare the resulting filters of a), b), and c). How do the filters vary in terms of filter order, width of the transition region, passband ripple, and stopband ripple?

2. **Analog filter transformation**. Construct a Chebyshev Type I *analog lowpass* filter prototype with unity cutoff frequency and a passband ripple of 0.01, stopband ripple is 0.01 for the bandpass and bandstop filter. Hint: Use cheb1ap().
   a) Transform the prototype lowpass filter into a high pass filter with a cutoff frequency of 500 Hz. Show the magnitude response of your filter.
   b) Transform the prototype lowpass filter into a band-pass filter with cutoff frequencies at 1000Hz and 2000Hz. Show the magnitude response of your filter.
   c) Transform the prototype lowpass filter into a band-stop filter with cutoff frequencies at 1000Hz and 2000Hz. Show the magnitude response of your filter.

3. **Analog to Digital Filter Transformation**. Consider the analog lowpass filter constructed in 1-b). Assume Fs = 8000Hz.
   a) Convert the analog lowpass filter into a discrete time filter using the impulse-invariance technique. Show the magnitude response of your filter.
   b) Convert the analog lowpass filter into a discrete time filter using the bilinear transformation technique. Show the magnitude response of your filter.
   c) Construct a digital Chebyshev Type I filter that satisfies the specifications in 1) by using the digital filter design version of "cheby1". Compare the magnitude and phase response of the filter with that of 3-a) and 3-b). By default, what does Matlab use in designing an IIR filter from analog filters?

4. **Digital IIR Filter Design**. The first in the filter design process is to choose the type of filter approximation to be employed and then estimate

the order of the transfer function from the filter specifications. For example the command for estimating the order of a Butterworth filter is:

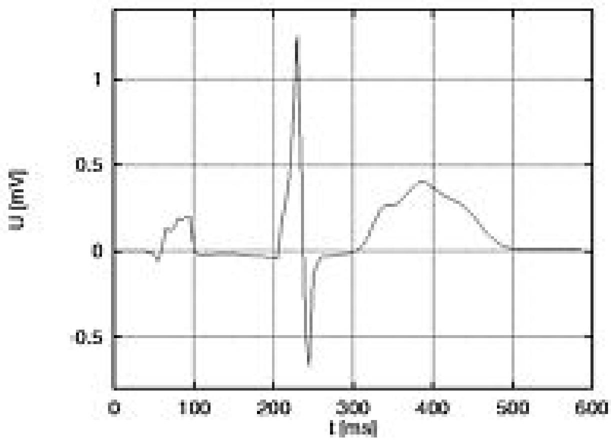
[N, Wn] = buttord(Wp, Ws, Rp, Rs),

where the input parameters are the normalized passband edge frequency Wp, the normalized stopband edge frequency Ws, the passband ripple Rp in dB, and the minimum stopband attenuation Rs in dB. Both Wp and Ws must be a number between 0 and 1 with the sampling frequency assumed to be 2 Hz. The output data are the lowest order N meeting the specifications and the normalized cutoff frequency Wn. If Rp = 3 dB, then Wn = Wp. buttord can also be used to estimate the order of a highpass, a bandpass, and a bandstop Butterworth filter. For a highpass filter design, Wp > Ws. For bandpass and bandstop filter designs, Wp and Ws are two-element vectors specifying both edge frequencies, with the lower edge frequency being the first element of the vector. In the latter cases, Wn is also a two-element vector. The other commands for the filter Chebychev Type I and Type II and the elliptic filters are cheb1ord(), cheb2ord and ellipord() respectively.

a. Using MATLAB determine the lowest order of a digital IIR lowpass filter of all four types (Butterworth, Chebyshev Type I and II and Elliptic). The specifications are as follows: sampling rate of 40 kHz, passband edge frequency of 8 kHz, stopband edge frequency of 16 kHz, passband ripple of 0.2 dB, and a minimum stopband attenuation of 60 dB. Comment on your results.
b. Implement the digital filter using the computed order and determine if the frequency response meets the above specifications.

5. (FOR GRADUATE STUDENTS ONLY) APPLICATION

An electrocardiogram (ECG) is an electrical signal generated by the heart. It is used to investigate and determine heart diseases. A clean electrocardiogram (ECG) signal resembles the figure below. Notice that it doesn't have a dc component.



An ECG signal stored in "ecg.sig" is sampled at 200Hz. It has been contaminated with noise coming from involuntary movement of the patient (low frequency noise) and from the analog circuitry used to record the ECG (high frequency noise).

a) Design an FIR filter that will remove the low and high frequency noise. Try to make the order of your filter as low as possible. Show the magnitude response and the output of your filter. What is the order of your filter?

b) Design a digital Chebyshev Type I filter that will remove the low and high frequency noise. Try to make the order of your filter as low as possible. Show the magnitude response and the output of your filter. What is the order of your filter?