Fall 2018 EE 313 Linear Systems and Signals Prof. Evans

Homework #7

Infinite Impulse Response (IIR) Filters

Assigned on Saturday, November 3, 2018
Due on Friday, November 9, 2018, by 5:00 pm via Canvas submission

Late homework is subject to a penalty of two points per minute late.

Reading: McClellan, Schafer & Yoder, *Signal Processing First*, 2003, Chapter 8.
Companion Web site with demos and other supplemental information: http://dspfirst.gatech.edu/
Web site contains solutions to selected homework problems from *DSP First*.

The e-mail address for Mr. Houshang Salimian (TA) is salimian.houshang@gmail.com.
Office hours for Mr. Salimian and Prof. Evans follow:

Time Slot	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
11:00 am		**Salimian (EER 0.814 Table #4)**		**Salimian (EER 0.814A)**	**Salimian (EER 0.814D)**
11:30 am		**Salimian (EER 0.814 Table #4)**		**Salimian (EER 0.814A)**	**Salimian (EER 0.814D)**
12:00 pm		**Salimian (EER 0.814 Table #4)**		**Salimian (EER 0.814A)**	**Salimian (EER 0.814D)**
12:30 pm		Evans (EER 1.516)		Evans (EER 1.516)	**Salimian (EER 0.814D)**
1:00 pm		Evans (EER 1.516)		Evans (EER 1.516)	
1:30 pm		Evans (EER 1.516)		Evans (EER 1.516)	
2:00 pm		Evans (EER 6.882)	Evans (EER 6.882)	Evans (EER 6.882)	
2:30 pm		Evans (EER 6.882)	Evans (EER 6.882)	Evans (EER 6.882)	
3:00 pm		Evans (EER 6.882)	**Salimian (EER 1.810)**	Evans (EER 6.882)	
3:30 pm			**Salimian (EER 1.810)**		
4:00 pm			**Salimian (EER 1.810)**		
4:30 pm					

Prof. Evans' coffee hours this week will be from 12:00-2:00pm on Friday in the EERC café.

EE 313 tutoring is available on Sundays through Thursdays from 7:00pm to 10:00pm in EER 0.814:
http://www.ece.utexas.edu/undergraduate/tutoring

***** ASSUME THAT ALL FILTERS IN THIS HOMEWORK SET ARE LINEAR AND TIME-INVARIANT. *****

1. Transfer Function, Difference Equation and Frequency Response Connections. ***50 points.***

Signal Processing First, problem P-8.14, page 240.

In addition, for each linear time-invariant filter $\mathcal{S}_1$, $\mathcal{S}_2$, $\mathcal{S}_3$, $\mathcal{S}_4$, $\mathcal{S}_5$, $\mathcal{S}_6$, and $\mathcal{S}_7$,

i. plot the poles and zeros of the transfer function in the z-domain, as explained below;
ii. plot the magnitude response, as explained below; and
iii. indicate the frequency selectivity as lowpass, highpass, bandpass, bandstop, allpass or notch.

Plotting poles and zeros: For each filter, plot the poles and zeros for the transfer function in the z-domain using Matlab (see below) and try to infer the frequency response from their location. This will help you reinforce what we covered in lecture on Thursday, November 1st, on the connections among time, frequency and z domains. Concerning these connections, I recorded a YouTube video in spring 2014 for the Real-Time Digital Signal Processing Laboratory course. Please watch from the 1:29 mark to the 22:25 mark and from 43:01 to the end (50:51 mark) at

https://www.youtube.com/watch?v=WWEKNvvJBvs&list=PLaJppqXMef2ZHIKM4vpwHIAWyRmw3TtSf

In Matlab, we can use `zplane(numer, denom)` where `numer` is a vector of feedforward coefficients $[b_0 \;\; b_1 \;\; \ldots \;\; b_M]$ and `denom` is a vector of feedback coefficients $[1 \;\; -a_1 \;\; -a_2 \;\; \ldots \;\; -a_N]$. The coefficients can be found from the numerator and denominator of the z-domain transfer function:

$$H(z) = \frac{b_0 + \; b_1 \, z^{-1} + \; b_2 \, z^{-2} + \cdots}{1 - \; a_1 \, z^{-1} - \; a_2 \, z^{-2} - \cdots}$$

which corresponds to the difference equation

$$y[n] - a_1 \, y[n-1] - a_2 \, y[n-2] - \cdots = b_0 \, x[n] + b_1 \, x[n-1] + b_2 \, x[n-2] + \cdots$$

```
% Filter S1.
% Observation of x[n] and y[n] for n >= 0:
%
% y[n] = 0.9 y[n-1] + (1/2) x[n] + (1/2) x[n-1]
%
% We can move the term 0.9 y[n-1] to the left-hand side:
%
% y[n] - 0.9 y[n-1] = (1/2) x[n] + (1/2) x[n-1]
%
% We'll take the z-transform of both sides.  All initial
% conditions are zero as a necessary condition to satisfy
% linearity and time-invariance for the system.
%
% Y(z) - 0.9 z^(-1) Y(z) = (1/2) X(z) + (1/2) z^(-1) X(z)
% (1 - 0.9 z-1) Y(z) = (1/2) X(z) + (1/2) z^(-1) X(z)
% H(z) = Y(z) / X(z)
%      = ( (1/2) + (1/2) z^(-1) ) / ( 1 - 0.9 z^(-1) )
%
%  i. Plot the poles and zeros in the z domain.
feedforwardCoeffs = [ 1/2 1/2 ];
feedbackCoeffs = [ 1 -0.9 ];
figure;
zplane(feedforwardCoeffs, feedbackCoeffs);
```

Plotting the magnitude response: Plot the magnitude response for each filter $\mathcal{S}_1$, $\mathcal{S}_2$, $\mathcal{S}_3$, $\mathcal{S}_4$, $\mathcal{S}_5$, $\mathcal{S}_6$, and $\mathcal{S}_7$ using `freqz(numer, denom)`. You can use the following code to plot the magnitude response in linear units over $-\pi \leq \omega \leq \pi$ to match the plots in Figure P-8.14:

```
% ii. Plot the magnitude response in linear units
%     over the interval -pi <= w <= pi.
W = -pi : 0.001 : pi;
[H, W] = freqz( feedforwardCoeffs, feedbackCoeffs, W );
figure;
plot(W, abs(H));
```

2. Equalization. 50 points.

Signal Processing First, problem P-8.22, page 244.

Although not graded, please review the solution to problem 6.4 from fall 2017 at

http://users.ece.utexas.edu/~bevans/courses/signals/homework/fall2017/solution6.pdf

As stated on the course descriptor, "Discussion of homework questions is encouraged. Please be sure to submit your own independent homework solution."

NOTE: In your solutions, please put all work for problem 1 together, then all work for problem 2 together, etc. Please see additional homework guidelines on the homework page.

Please read the homework guidelines at
http://users.ece.utexas.edu/~bevans/courses/signals/homework/index.html