EE 480 L DIGITAL SIGNAL PROCESSING

LABORATORY 8: IIR FILTERS

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1. OBJECTIVE

Review IIR filters with practical applications.

2. BACKGROUND

In previous assignments, convolution was used to implement finite impulse response (FIR) linear time invariant (LTI) filters. If the filter had an impulse response of length N, then the filter required a maximum N multiplies, $N-1$ adds and $2N$ memory locations to compute each output. Consequently, convolution is an impractical method for implementing an infinite impulse response (IIR) filter because it would require an infinite number of multiplies, adds and memory locations to compute each output sample. A class of LTI IIR systems can be implemented with recursive linear constant coefficient difference equations (LCCDE).

3. COMPONENTS & EQUIPMENT

PC with MATLAB/Octave GNU installed.

4. LAB DELIVERIES

PRELAB:

1. **Review Fourier Transform, Z-Transform and IIR.**

LAB EXPERIMENTS:

1. Resonator.

a) Determine a LCCDE which has an impulse response of

$$h[n] = r^n \cos(\omega_0 n)\, u[n], \text{ where } \omega_0 = \pi/10,\ n \geq 0.$$

Using MATLAB ***freqz*** function, plot magnitude of the frequency response for this system when $r = 0.99$.

b) Write a MATLAB script to implement your LCCDE (Table of common Z-transform pairs). Calculate the first 251 samples of the zero-state response (ZSR) of your difference equation when the input $x[n] = \cos(\omega_0 n)\, u[n]$, and

i) $r = 0.99$

ii) $r = 1$

iii) $r = 1.01$

c) Use your script in b), and calculate the first 251 samples of the zero-input response (ZIR) of your difference equation when $y[-1] = 4, y[-2] = 4$, and $r = 0.99$, 1, 1.01, respectively.

d) Use your script in b), and find the total response of your difference equation when $y[-1] = 4$, $y[-2] = 4$, the input is $x[n] = \cos(\omega_0 n)\, u[n]$, and $r = 0.99$, 1, 1.01, respectively. Compare your result with the summation of b) and c). Comment on your comparison.

e) Using ***filter*** function in MATLAB, repeat b).

2. IIR Frequency Selective Filters

The following is the system function of a causal lowpass IIR filter.

$$H(z) = \frac{0.00183555(1 + z^{-1})^4}{1 - 3.05434z^{-1} + 3.8289993445z^{-2} - 2.29245273626z^{-3} + 0.550744355605z^{-4}}$$

a) Using MATLAB function ***freqz***, plot the frequency response of this system.

b) Using MATLAB function ***roots***, determine the poles of this system. Using either MATLAB or a hand sketch, make a pole zero plot of $H(z)$. Assuming that the system is causal, what can you say about the filter's stability and why?

c) Generate and plot the first 101 samples of the following sequences.

i) $a[n] = \cos[(\pi/8)n]\, u[n]$

ii) $a[n] = \cos[(\pi/8)n]\, u[n] + \cos[(\pi/3)n]\, u[n]$

d) Using MATLAB ***filter*** function, filter signals $a[n]$, $b[n]$. Plot and explain your results.

3. All-Pass System

Consider the following all-pass system function.

$$H_{ap}(z) = \frac{z^{-1} - a}{1 - az^{-1}} \cdot \frac{(bb^*) - (b + b^*)z^{-1} + z^{-2}}{1 - (b + b^*)z^{-1} + bb^* z^{-2}}$$

where $a = 0.9$, $b = 0.9\exp\,(j\pi/3)$ and the symbol * denotes complex conjugate. (Note the difference between .' and ' when transposing vectors with complex elements.)

https://www.mathworks.com/help/matlab/ref/transpose.html

https://www.mathworks.com/help/matlab/ref/ctranspose.html

a) Using MATLAB ***freqz*** function, plot the frequency response (both magnitude and phase).

b) Using MATLAB ***grpdelay*** function, plot the group delay of this system.

c) Generate and plot the first 101 samples of the sequence, $d[n]$, where

$$d[n] = \frac{1}{2} + \frac{1}{\pi}\sum_{k=1}^{7}\frac{1}{k}\sin(k\omega_0 n)$$

and $\omega_0 = \pi/10$. Also plot the magnitude of the frequency spectrum of $d[n]$.

d) Using MATLAB ***filter*** function, filter signal $d[n]$. Plot the output sequence and the magnitude of its frequency spectrum. Comment on your results.

POSTLAB REPORT:

Include the following elements in the report document:

<table>
<tr><th>Section</th><th colspan="2">Element</th></tr>
<tr><td>1</td><td colspan="2">Theory of operation
Include a brief description of every element and phenomenon that appear during the experiments.</td></tr>
<tr><td>2</td><td colspan="2">Prelab report
1. None</td></tr>
<tr><td rowspan="5">3</td><td colspan="2">Results of the experiments</td></tr>
<tr><th>Experiments</th><th>Experiment Results</th></tr>
<tr><td>1</td><td>Screenshots of MATLAB codes, outputs, figures, etc.</td></tr>
<tr><td>2</td><td>Screenshots of MATLAB codes, outputs, figures, etc.</td></tr>
<tr><td>3</td><td>Screenshots of MATLAB codes, outputs, figures, etc.</td></tr>
<tr><td rowspan="3">4</td><td colspan="2">Answer the questions</td></tr>
<tr><th>Questions</th><th>Questions</th></tr>
<tr><td>1</td><td>Any differences do you observe of using filter vs. convolution?</td></tr>
<tr><td>5</td><td colspan="2">Conclusions
Write down your conclusions, things learned, problems encountered during the lab and how they were solved, etc.</td></tr>
<tr><td>6</td><td colspan="2">Images</td></tr>
</table>

	Paste images (e.g. scratches, drafts, screenshots, photos, etc.) in Postlab report document (only .docx, .doc or .pdf format is accepted). If the sizes of images are too large, convert them to jpg/jpeg format first, and then paste them in the document. **Attachments (If needed)** *Zip your projects. Send through WebCampus as attachments, or provide link to the zip file on Google Drive / Dropbox, etc.*

5. REFERENCES & ACKNOWLEDGEMENT

1. https://matlabacademy.mathworks.com/
2. https://www.tutorialspoint.com/matlab/
3. https://en.wikipedia.org/wiki/Z-transform

I appreciate the help from faculty members and TAs during the composing of this instruction manual. I would also thank students who provide valuable feedback so that we can offer better higher education to the students.