Full Name: ____

EEL 3135 (Spring 2025) – Lab #04

Submission Notes

- Your laboratory solutions should be submitted on Canvas as a single published MATLAB PDF.
- Use the provided skeleton code as the basis for your solutions (easier for you and the graders).

Question #1: *(Convolution)*

Download `EEL3135_lab04_comment.m` from Canvas, replace each of the corresponding comments with the corresponding descriptions. This is designed to show you how to work with audio and images using convolution in MATLAB. **Note:** You should run the code to help you understand how it works and help you write your comments. You will use elements of this MATLAB code in the rest of the lab assignment.

Question #2: *(Echo and Ring Modulation)*

This question will implement both an echo effect and an ring modulation effect on audio.

(a) Create a function `y = echo(x, s, A)` that outputs the following signal:

$$y[n] = x[n] + Ax[n-s] \ ,$$

where `A` is the echo amplitude and `s` is the echo delay. You may want to use the `shift` function in Question #1. Include the `echo` function at the end of the skeleton file.

(b) Apply `echo` to your input `x` in the skeleton code to get output `xr`. Set the delay to $s = 20000$ samples and amplitude to $A = 0.5$. **Submit this audio as a b_echo.wav file.**

(c) **Answer in your comments:** If our sampling frequency is 44100 samples per second, and we are delaying by 20000 samples, how long is the delay on the signal in seconds?

(d) Create a function `y = ring_modulator(x, m, A)` that outputs the following signal:

$$y[n] \quad = Ax[n]\cos(2\pi mn)$$

where `A` is the amplitude and `m` is the modulation frequency.

(e) Apply `ring_modulator` to input `x` in the skeleton code to get output `xt`. Set amplitude to `A = 1` with both `m = 1/1250` and `m=1/250`. **Submit audio as e_modulator1.wav and e_modulator2.wav file for $m = 1/1250$ and $m = 1/250$, respectively.**

(f) **Answer in your comments:** How does the ring modulation affect the audio and why? Show this mathematically.

(g) A system is not linear if the system $\mathcal{T}\{\cdot\}$ satisfies [1]

$$\mathcal{T}\{ax[n]\} \neq a\mathcal{T}\{x[n]\}$$

Test this with $a = 10$ and the `echo` and `ring_modulator` with the parameters from (b) and (e). **Answer in your comments:** Based on these results, which systems are linear? How do you know? [2]

[1] This is a simplified form of linearity for the sake of convenience of demonstration.

[2] Note: you may not be able to hear difference differences, so you may need to take a different approach.

(h) A system is time-varying if the system $\mathcal{T}\{\cdot\}$ satisfies

$$\mathcal{T}\{x[n-N]\} \neq y[n-N] \qquad \text{such that} \qquad \mathcal{T}\{x[n]\} = y[n]$$

Use `shift` function in Question #1 to shift outputs from (b) and (e) by $N = 4000$ samples. Then shift your input `x` by $N = 4000$ samples to get `xs`. Input `xs` into `echo` and `ring_modulator` with the parameters from (b) and (e). **Answer in your comments:** Based on these results, which systems are time-varying? How do you know? [3]

Question #3: *(Image Filtering)*

Spatial filtering is often used to modify images. We can regard the image as an input signal and the spatial filter is our system. The output of this system is obtained by doing convolution between the input image $g[x, y]$ and the filter impulse response $w[u, v]$. The output pixel $f[x, y]$ with 3×3 filter can be obtained by the 2-dimensional convolution

$$f[x, y] = \sum_{s=-1}^{1} \sum_{v=-1}^{1} w[u, v] g[x-u, y-v].$$

For this question, add all code into skeleton `eel3135_lab04_skeleton.m` from Canvas. Include all code (and functions) in this one file so that everything is published to a single PDF.

(a) Consider the filter impulse response (also known as a kernel) below. Apply this filter to the image `img`. Use Question #1 as a guide.

$w[-1,-1]$	$w[-1,0]$	$w[-1,1]$
$w[0,-1]$	$w[0,0]$	$w[0,1]$
$w[1,-1]$	$w[1,0]$	$w[1,1]$

=

-2	-1	0
-1	1	1
0	1	2

After applying the filter, normalize the image by subtracting its minimum value and then (sequentially, not simultaneously) dividing its maximum value and multiplying by 255. This should force its value to range 0 to 255. Refer to the output of these operations as $f_1[u, v]$. Use `imagesc` and `subplot` to plot the image before and after applying the processing.

(b) **Answer in your comments:** Does this filter blur, sharpen, or extract edges in the image? How / why do you know that from the impulse response / kernel?

(c) Perform a thresholding operation on $f_1[u, v]$ such that

$$f_2[u, v] = \begin{cases} 1 & f_1[u, v] > 140 \\ 0 & \text{otherwise} \end{cases}$$

(d) Apply the new filter below to $f_2[u, v]$. Use `imagesc` and `subplot` to plot the image before and after applying the filter.

$w[-1,-1]$	$w[-1,0]$	$w[-1,1]$
$w[0,-1]$	$w[0,0]$	$w[0,1]$
$w[1,-1]$	$w[1,0]$	$w[1,1]$

=

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

(e) **Answer in your comments:** Does this filter blur, sharpen, or extract edges in the image? How / why do you know that from the impulse response / kernel?

[3] Note: you may not be able to hear difference differences, so you may need to take a different approach.