ECE355L Signals and Systems Lab

Project 3: Convolution of Signals

Report due: two weeks

Part 1: Convolution Calculations:

The main use of convolution in engineering is in describing the output of a linear, time-invariant (HYPERLINK "http://en.wikipedia.org/wiki/LTI_system_theory"LTI HYPERLINK "http://en.wikipedia.org/wiki/LTI_system_theory") system. The input-output behavior of an LTI system can be characterized via its impulse response, and the output of an LTI system for any input signal *x(t)* can be expressed as the convolution of the input signal with the system's impulse response.

In Matlab, we are convolving vectors containing a finite number of elements, rather than continuous signals defined on the entire real axis. In essence, we are performing the following approximation.

$$c(t) = f(t) * g(t) = \int_{-\infty}^{\infty} f(\tau) g(t-\tau) d\tau \cong c(m\Delta\tau) = \sum_{n=-\infty}^{\infty} f(n\Delta\tau) g(m\Delta\tau - n\Delta\tau)\Delta\tau$$

When we convolve two vectors *a* and *b* containing A and B elements respectively the resulting vector is length A+B–1. If *a* and *b* are vectors of polynomial coefficients, convolving them is equivalent to multiplying the two polynomials. When *f(t)* is known to be zero except in the interval , and *g(t)* is known to be zero except in the interval , the convolution *y(t)=f(t)*g(t)* is constrained to be zero except in the interval .

Example 1) Plot the following signals on the same window, but separate graphs using the *subplot* command. Let $-1 \leq t \leq 3$ with a step size of 0.001 for *f(t)* and *g(t)*. The convolution product, *y*(*t*), will then be evaluated for $-2 \leq t \leq 6$.

(a) $f(t) = u(t) - u(t-2)$

(b) $g(t) = u(t) - u(t-2)$

(c) $y(t) = f(t) * g(t)$

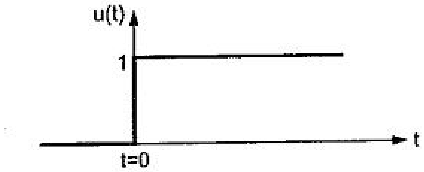
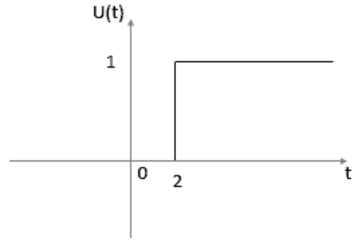


Fig. 2.5 Unit step function

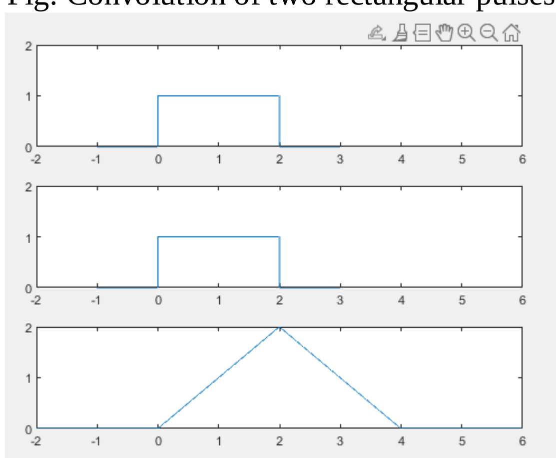


U(t-2)

Code:

```
dt = 0.001;
t = -1:dt:3;
f = rectpuls((t - 1)/2);
g =  f;
y = dt*conv(f, g);
t1 = -2:dt:6;
subplot(3,1,1), plot(t,f), axis([-2 6 0 2]);
subplot(3,1,2), plot(t,g), axis([-2 6 0 2]);
subplot(3,1,3), plot(t1,y), axis([-2 6 0 2]);
```

Fig: Convolution of two rectangular pulses



Example 2) Plot the following signals on the same window, but separate graphs using the *subplot* command. Let $-1 \leq t \leq 4$ with a step size of 0.001 for *f(t)* and *g(t)*. The convolution, $y(t)$, product will then be evaluated for $-2 \leq t \leq 8$.

(a) $f(t) = u(t) - u(t-1)$

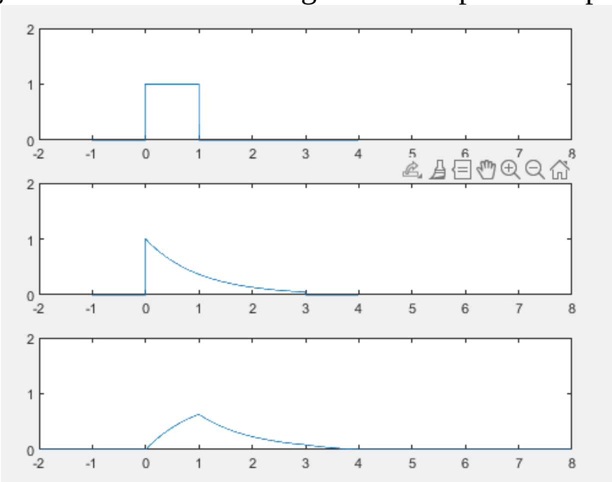
(b) $g(t) = e^{-t}(u(t) - u(t-3))$

(c) $y(t) = f(t) * g(t)$

```
dt = 0.001;
t = -1:dt:4;
f = rectpuls(t - 0.5);
```

```
g =  exp(-t).*rectpuls((t-1.5)/3);
y = dt*conv(f, g);
t1 = -2:dt:8;
subplot(3,1,1), plot(t,f), axis([-2 8 0 2]);
subplot(3,1,2), plot(t,g), axis([-2 8 0 2]);
subplot(3,1,3), plot(t1,y), axis([-2 8 0 2]);
```

Fig: Convolution of rectangular and exponential pulse



Exercises

Please complete these exercises. Please submit the project 3 report at D2L by 04/04/2024 i should include the results and commands that you used in these exercises.

1.Plot the respective graphs for the above examples and include in the report.

2. Plot the following signals on the same window, but separate graphs using the *subplot* command and *axis* so that all graphs have the same range for the time (as was done in the examples). Let $-2 \le t \le 25$ with a step size of 0.001 for $f(t)$ and $g(t)$. The convolution, $y(t)$, product will then be evaluated for $-4 \le t \le 50$.

(a) $f(t) = \sin\left(\frac{t\pi}{10}\right) \times \left[u(t) - u(t-20)\right]$

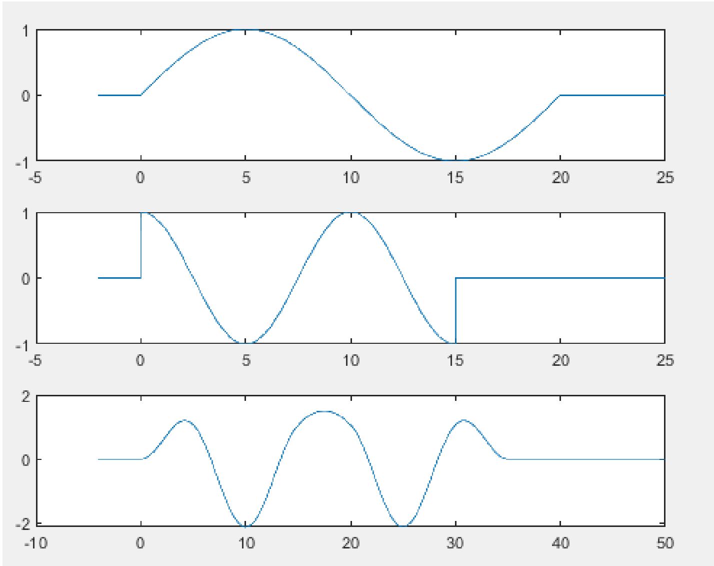
```
f = sin(0.1*t*pi).*rectpuls((t - 10)/20);
```

(b) $g(t) = \cos\left(\frac{t\pi}{5}\right) \times \left[u(t) - u(t-15)\right]$

```
g = cos(0.2*t*pi).*rectpuls((t - 7.5)/15);
```

(c) $y(t) = f(t) * g(t)$

Sample plots of Question 2.

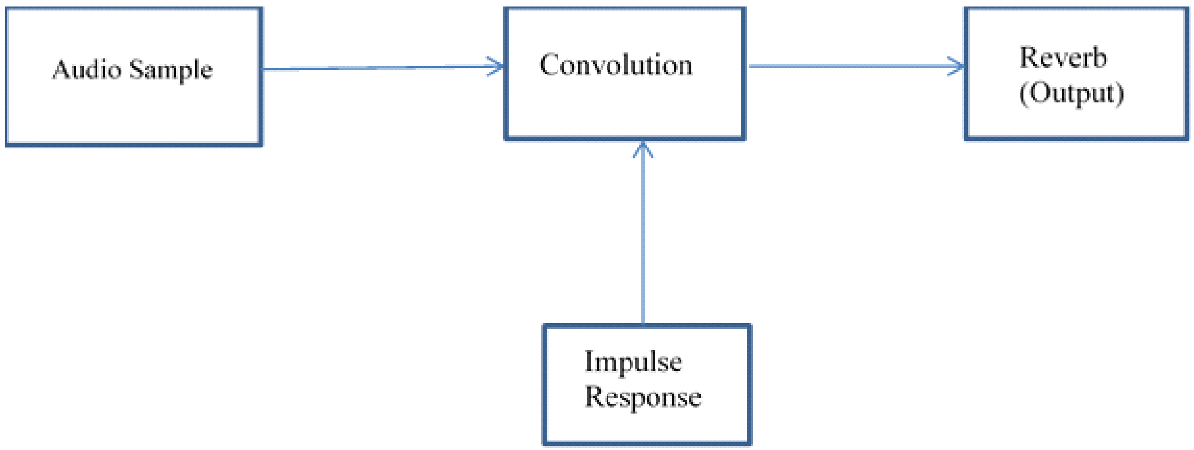


Part II: Convolution reverb

The technique has been widely used to simulate a reverberation of a physical space. This is done by convolving an audio signal with the impulse response *h(t)* of the physical space (rooms, hallways, etc.). In this project, you are going to use a clean audio signal and two impulse response signals *h(t)* of a large hall and a small hall to obtain the reverberated audio signals respectively.

The clean audio signal (*audio_sample.wav)* is an excerpt from Episode 567 of *This American Life* podcast. Two impulse response signals (*impulse_response1.wav* for the lager hall and *impulse_response2.wav* for the small hall) were obtained from website "Samplicity's original and highly acclaimed impulse responses (http://www.samplicity.com/bricasti-m7-impulse-responses/)".

Apply convolution to obtain the reverberated audio signals. You can hear the differences between the original audio signal and the reverberated audio signal. You can also compare the difference of the reverberated audio signals in a large hall and in a small hall.



Exercises

Please complete these exercises and submit your solutions at D2L by 04/11/2024. The results should include followings.

- Input signals: In the project 4 assignment folder at D2L, you'll find three audio files: audio_sample.wav, impulse_response1.wav and impulse_response2.wav. Please download three wav files and save them in your folder.
- Develop a Matlab code to convolve the audio signal with two different impulse response signals.
- Compare the audio signal with two different impulse response signals. Use *sound* command to hear the audio signals. **(Note: Please reduce the volume of the speaker to avoid very loud sound)**. Please describe the differences between to audio signals.
- Plot the original audio signal, impulse response signals, and the convolved output signals.

Sample Codes for your information.

```
clear all

%input the original audio signal and inpulse response signals obained from
%a large hall and a small hall
[a,fs] = audioread('audio_sample.wav');
[h1,fs] = audioread('impulse_response1.wav'); %large hall
[h2,fs] = audioread('impulse_response2.wav'); %small hall

sound(a,fs);
pause(5);sound(h1,fs);
pause(5);sound(h2,fs);
```

```
conv_rev1 = conv(a,mean(h1,2));
pause(5);sound(conv_rev1,fs)
conv_rev2 = conv(a,mean(h2,2));
pause(5);sound(conv_rev2,fs)


t1 = 0:1/fs:(length(a)/fs)-(1/fs);
t2a = 0:1/fs:(length(h1)/fs)-(1/fs);
t2b = 0:1/fs:(length(h2)/fs)-(1/fs);
t3a = 0:1/fs:((length(a)+length(h1)-1)/fs)-(1/fs);
t3b = 0:1/fs:((length(a)+length(h2)-1)/fs)-(1/fs);

subplot(2,3,1);
plot(t1,a),xlabel('Time(s)'),ylabel('Amplitude'),title('Original audio
sample');
subplot(2,3,2)
plot(t2a,h1),xlabel('Time(s)'),ylabel('Amplitude'),title('Impulse response 1
(Large Room)')
subplot(2,3,3)
plot(t3a,conv_rev1), xlabel('Time(s)'),ylabel('Amplitude'),title('Convoluted
audio sample for a large room')
subplot(2,3,4);
plot(t1,a),xlabel('Time(s)'),ylabel('Amplitude'),title('Original audio
sample');
subplot(2,3,5)
plot(t2b,h2),xlabel('Time(s)'),ylabel('Amplitude'),title('Impulse response 2
(small Room)')
subplot(2,3,6)
plot(t3b,conv_rev2), xlabel('Time(s)'),ylabel('Amplitude'),title('Convoluted
audio sample for a small room')
```