ECE280 - Lab 3: Digital Audio Effects

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I have adhered to the Duke Community Standard in completing this assignment.

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1 Introduction

Objectives:

1. Understand and implement single echo filters in Simulink
2. Understand and implement reverberation filters in Simulink
3. Understand and implement flanging effect in SImulink
4. Gain familiarity with Simulink DSP system and audio toolboxes
5. Understand difference equations

2 Background

- **Single Echo**:
  A single echo is an effect that outputs the original input signal plus an additional delayed version of the input signal at a lower amplitude creating a single echo.
- **Reverberation**:
  Reverbation is an effect that creates a loop of echoes by outputting the original input signal plus a delayed version of the output signal at a lower amplitude creating a constant feedback loop.
- **Flanging**:
  Flanging is an effect that adds a jet-like sound intensity to the input signal as a result of playing the input sound with another version of the input sound at a lower amplitude and varying (small) delay.

3 Results and Discussion

1. Make observations about what you heard in each case.

   In exercise 1, the wave signal by the function generator created the sound of a single note when played in Simulink. The output of the "Tones.wav" file was a repeating piece of music that sounded like 4 repeating notes.

   In exercise 2, the Hello.wav played a message asking, "Hello, how are you doing today?" When the echo was implemented, the sound output played the original first message and a delayed version at a lower volume. However, the single echo filter in real time created high pitched noises at high volumes that made it hard to distinguish the significant output among the noise.

   In exercise 3, reverberation created repeating echoes of the message in Hello.wav. In addition, the allpass reverbation filter was observed to be more "natural" than the simple reverbation filter. Reverbation in real time also created high pitched noises at high volumes that made it hard to distinguish the significant output among the noise; there was less noise in the allpass reverbation filter.

   In exercise 4, the flanging effect added to the intensity of the message in the Hello.wav file. The intensity was like that of a jet launching. Similar to previous exercises, the real-time version had very loud noises, that made it hard to assess the impact of the effect.

2. Describe what changing the coefficients in the difference equations did to the observed sound.

   In exercise 1, there was no changing of coefficients. In exercise 2, lowering the coefficient in the echo equation lowered the volume of the echoed sound; raising it increased the volume of the echoed sound. In exercise 3, modifying the coefficients had the same effect as that in exercise 2: higher coefficients resulted in higher echo volumes. Similarly, in exercise 4, the higher the coefficients, the more intensive the sound output was.

3. **Single Echo Effect** Results and Discussion.

   - Describe how the SimuLink model is related to the difference equation.
     The Simulink model implements the difference equation for the echo by splitting the input sound into two versions: an unmodified version (x[n]) and a version that endures a delay using the delay block and reduction in amplitude using the gain block (ax[n-D]). The two versions are added together (using the add block) resulting in an echo (x[n]+ax[n-D]).
   - What do you hear when a signal is processed using the single echo system?
     The output heard is the same signal being processed plus a delayed version at a lower amplitude.
   - What effect does changing the parameter, a, have on the output signal?
     Changing this parameter changes the amplitude/volume of the delayed sound. The higher this parameter is, the higher the volume of the delayed sound; the lower it is, the lower the volume of the delayed sound.
   - What effect does changing the parameter, D, have on the output signal?
     Changing this parameter affects when the delayed sound is played. The higher this parameter is, the later the delayed sound is played; the lower it is the earlier the delayed sound is played.
   - Why does the output sound this way?
     The output sounds this way because the original signal being processed plus a delayed version at a lower amplitude are added and played together. The parameter a controls the amplitude of the delayed signal. The parameter D controls the shift in horizontal axis (time) of of the echoed signal.
   - Provide an analytic expression and a sketch for the impulse response, $h[n]$, of the single echo system.
     h[n] $= \delta[n] + a\delta[n-D]$

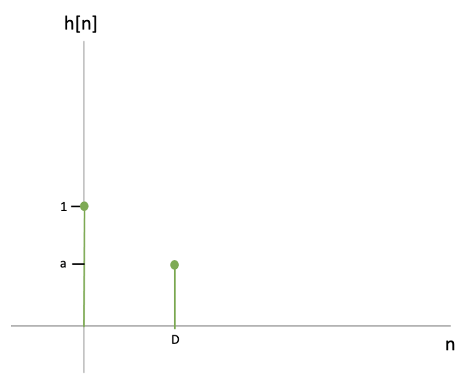

Figure 1: Single Echo Impulse Response Sketch

4. How can you interpret $h[n]$ in terms of your observations?
   The convolution of any signal with this h[n] creates an output signal that is the sum of the original input signal plus a delayed version of the input signal at a lower amplitude.

5. Assuming a sampling rate of $8000Hz$, how would you choose the delay, D, to achieve a time delay of 0.25 seconds?
   There is a sampling interval of 0.125 milliseconds/sample. To create a delay of 0.25 seconds, the exponent of z in the delay block should be set to 2000

6. Is the single echo effect system memoryless?
   No, it's not memoryless because it depends on past values.

7. Is the single echo effect system casual?
   Yes, it's causal because it only depends on past and present values.

8. Is the single echo effect system stable?
   Yes, it's stable. Given x[n] is stable nothing causes it to becomee unstable.

9. Is the single echo effect system time invariant?
   The system is time invariant because a time shift in the input signal will create a corresponding time-shift in the output signal (i.e., not dependent on absolute time).

10. Is the single echo effect system linear?
    The system must be linear because it only consists of linear operations: addition, scaling, and delays/-time shifting. Furthermore, it passes both the homogeneity and additivity tests: A(x[n]+ax[n-D]) + B(x[n]+ax[n-D]) = A*x[n]+A*ax[n-D]) + B*x[n]+B*ax[n-D].

Reverberation Results and Discussion.

- Describe how the SimuLink model is related to the difference equation.
  The Simulink model implements the difference equation for reverbation by using an add block to sum an unmodified version of the input signal (x[n]) with a delayed output of the adder at a lower amplitude using the gain block (ay[n-D]). The output of the adder is continuously fed to the adder after enduring a delay and an amplitude reduction (x[n]+ay[n-D]).
- What do you hear when a signal is processed using the simple reverberation system?
  A repetitive loop of echoes at decreasing amplitudes is heard.
- What effect does changing the parameter a have?
  Changing this parameter changes the amplitudes of the delayed sounds. The higher this parameter is the higher, the volume of the repeated echoes; the lower it is the lower the volume of the delayed echoes. Another way to interpret this parameter is understanding that it controls the speed of decay of the amplitude of repeating echoes.
- What effect does changing the parameter D have?
  Changing this parameter affects when the delayed echoes are played. The higher this parameter is, the later the delayed sounds are played after the input signal; the lower it is, the earlier the delayed sounds are played after the input signal.
- Compare the simple reverberation filter with the single echo filter with the same delay and gain. How do they differ? Both filters utilize delays and amplitude reductions to create an "echo" effect. However, the single echo filter creates a single echo by only manipulating the input sound/signal; the simple reverberation filter, on the other hand, creates several echoes by manipulating the output and creating a constant feedback loop.
- Compare the simple and allpass reverberators. How are they similar? How are they different? Why do you think the allpass reverberator sounds more natural?
  Both filters create a constant feedback loop and use delays and amplitude reduction to create repeating echoes. However, the allpass reverberator filter utilizes wave reflection by using a gain block with gain of -1 that the simple reverberator filter does not. This wave reflection results in the allpass reverberator echoes sounding more "natural" because sound waves in the real world get reflected when they bounce off a surface in an echo.

Flanging:

- What do you hear when a signal is processed using the flanging system?
  The flanging system makes the message in the Hello.wav ("Hello, how are you doing today?") sound intensive(similar to the intensity of a jet launching). The Simulink model implements the difference equation by splitting the input signal into two versions: one that remains unmodified (x[n]) and another that has its amplitude reduced by the gain block and is delayed by varying amounts using sine wave, dsp constant, sum, and variable fractional delay blocks (ax[n-D] where D is varying). The two versions are summed together creating two signals that are delayed with a changing period.
- What effect does changing the gain, delay, and flange frequency have?
  The gain affects how high the amplitude/volume of the flange effect is (higher gain results higher volume). The delay affects when the spacing between the original input sound and the flange sound.

The higher the delay the greater the spacing between the input signal and the modified input signal. The flange frequency affects the pitch of the flange effect. The higher the frequency, the higher pitched the sound output is. The lower the frequency, the deeper and more jet-like the sound output is.

- Plot the low-frequency oscillator, $d(n)$, for these parameters: $D = 4000$ samples, $f_s = 8000$ Hz, $f_d = 2000$ Hz.

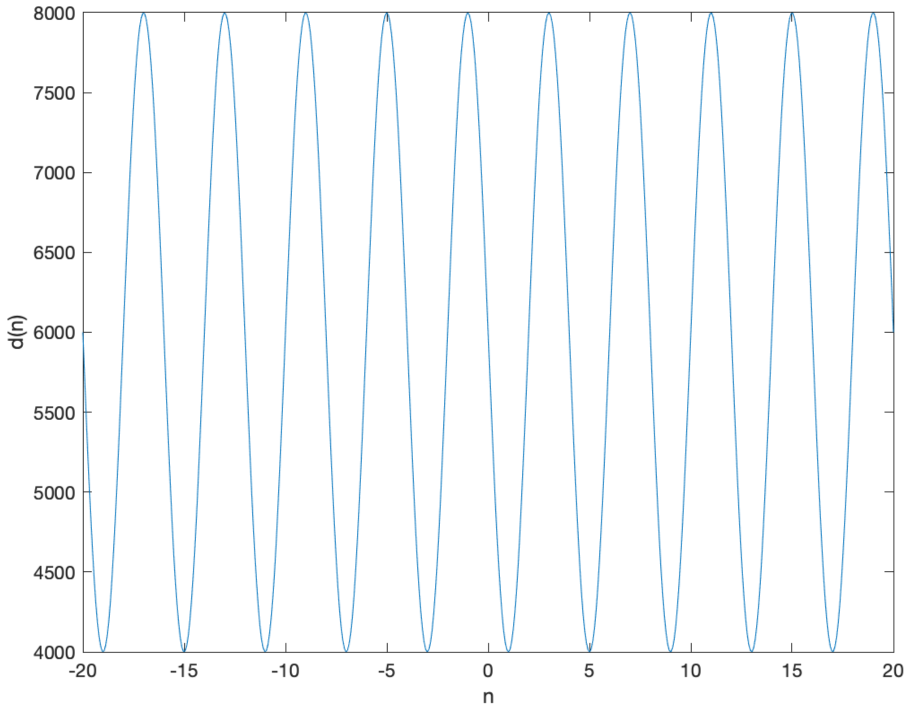

Figure 2: Low frequency oscillator (d(n) as function of n)

- What is the maximum delay when $D = 4000$ samples and $f_s = 8000$? What is the minimum delay? The maximum delay is 8000 as shown in figure 2. The minimum is 4000 as shown in figure 2.

4 Conclusions

In this laboratory, experience was gained in sound effects: single echo, reverberation, and flanging. In addition, Simulink blocks were used to implement difference equations for the different sound effects. Furthermore, the impulse response for the single echo filter was interpreted and plotted.