Homework #6: Reverberation Analysis & Synthesis
Due Date: May 24, 2012

Submission Instructions

Submit via coursework's DropBox. Create **a single compressed file** (`.zip`, `.tar` or `.tar.gz`) containing all your submitted files. Place the compressed file at the top level of your Drop Box. Name the file using the following convention:

`<suid>_hw<number>.zip`

where `<suid>` is your Stanford username and `<number>` is the homework number. For example, for Homework #1 my own submission would be named `jorgeh_hw1.zip`.

Each problem should be in its own subfolder, ideally named `problemX`. Therefore, if different problems ask to to modify the same code, you'll have to turn in different projects, one for each problem.

What to submit?

· Matlab problems: submit all the files necessary to run your code.

· VST implementations: only submit the corresponding `.h` and `.cpp` files.

· Theory problems: submit the solutions in **PDF format only**. LaTeX or other equation editors are preferred, but scans are also accepted. In case of scanned handwriting, make sure the scan is legible.

1 Problem Set

In this problem set you will first analyze the space and recordings made at Memorial Church to characterize its reverberation. Then, based on this analysis, you will synthesize an Impulse Response to simulate the space in Memorial Church.

The files provided contain the response of the church to different balloon pops and noise bursts, recorded using the AKG-414 microphones in an omni-figure 8 configuration, placed in the crossing center of the church.

The recordings are not post-processed, with the exception of one balloon pop, which was amplified. Each channel of the stereo file contains one of the microphone recordings. For the omni-figure 8 configuration, the left channel corresponds to the figure 8 mic recording and the right channel to the omni mic recording.

Problem 1. [40 points]

1(a) [20 points] Referring to the table of Sabine coefficients in §9 of the course notes and the air absorption decay rates a few pages later, estimate $T_{60}(\omega)$ for Memorial Church at 250 Hz, 1000 Hz and 4.0 kHz. Approximate the church as a totally enclosed shoebox, 25m wide, 40m long, 10m high. Use plywood for the ceiling and half the floor, use glass for about a tenth of the walls and plywood for another tenth, and assume marble for everything else.

1(b) [10 points] What if the church were half its size?

1(c) [10 points] What if the church floor were carpeted?

Problem 2. [40 points]

The file `filtered_noise.wav` contains the recorded response to a series of filtered noise bursts. The filters have center frequencies of 16 kHz, 8 kHz, 4 kHz, ... 125 Hz. For each of the individual noise burst responses, estimate the late field decay time in units of seconds per 60 dB of decay (Hint: you could use Matlab's `polyfit` function).

Problem 3. [120 points]

3(a) [5 points] Choose a balloon pop recording and plot the spectrogram of the first 2.5 seconds and of the first 300 milliseconds of one of the balloon response channels. Use 512-point long windows and a hop size of 32 points. You can use the function `ftgram.m` and/or `stft.m` provided.

3(b) [20 points] Use the Matlab function `butter` to create a set of octave-wide, third-order bandpass Butterworth filters, centered at 125 Hz, 250 Hz, ..., 16.0 kHz (to create your filter bank, we suggest you use the diadic Butterworth low-pass/high-pass decomposition we discussed in class, with transition frequencies at the geometric means of the band center frequencies, but alternatively you can use Butterworth band-pass filters for each of your bands). Turn in a plot showing their transfer function magnitudes. (Hint: Use Matlab's freqz function.)

3(c) [30 points] Apply each of the octave band filters you made to the balloon pop response. Use the Matlab function `filtfilt` which applies the filter twice, once forward in time and once backward in time, to create a zero-phase filter. Estimate the decay rate and T_{60} for each band by forming a running mean of the band energy, and computing the slope of the dB smoothed energy (using least-squares). Plot the results on a log frequency axis using `semilogx`. Repeat the procedure for a second balloon pop and compare the two chosen balloon pops in terms of their T_{60} per band.

3(d) [20 points] Find the maximum signal energy to mean noise energy ratio (the measurement SNR) for each band. To estimate the noise level, find the average noise energy before the arrival of the balloon pop.

Problem 4. [40 points]

Now you will synthesize an IR that perceptually matches the ballon pop response.

4(a) [20 points] Using one of the band-passed balloon pop responses, estimate the initial equalization for each frequency band. That is, estimate the power at the begining of the late field for each band separately.

4(b) [20 points] Using the set of octave-wide filters you designed in 3(b), the decay rates estimated in 3(c) and the EQ you just found, synthesize an impulse response that matches the chosen ballon pop. Turn in a spectrogram of the synthesized IR and verify that the decay rates and T_{60} values you measured for the balloon pop are correctly modeled by your IR synthesis.

Problem 5. [50 points]

Using the exponential sine sweep (`ssx_48_20.wav`) and its response (`ssx_20_response.wav`) recorded in memorial church, you can estimate the church's IR using this Matlab code:

```
%% exponential sweep IR estimate
[rs, fs] = wavread('ssx_20_response.wav');
[ss, fs] = wavread('ssx_48_20.wav');

cs = real(ifft(1./fft(ss)));
cs = cs(2^20-2^16+1:end);

irhatx = real(ifft((fft(cs, 2^21)*[1 1]).*fft(rs, 2^21)));
ftgram(irhatx(2^20+[1:5*fs],1), fs, 'rir');
```

5(a) [35 points] Replace the direct path and first reflection (reflection from the floor) with perfect impulses:

1. Crop the IR so the direct path start at $t = 0$
2. Identify the time at which the first reflection (t_r) occurs in the IR
3. Replace the direct path with an impulse followed by zeros and scale the impulse to match the energy in the direct path (total energy in the $[0, t_r]$ range
4. Similarly, replace the first reflection, again by scaling an impulse according the the first reflection's energy, followed by zeros
5. Window the rest of the IR, so it fades in some time after the first reflection. To do that use a window of the form

$$w(t) = \begin{cases} 0 & t < t_L \\ 0.5(1 + \cos(2 * \pi * t/0.004)) & t_L \leq t \leq t_L + 2\text{ms} \\ 1 & t > t_L + 2\text{ms} \end{cases}$$

(note that t is expressed in seconds)

6. Finally, add the two impulses and the windowed IR to form the modified IR.

Turn in a time domain plot and the spectrogram of the modified IR.

5(b) [**15 points**] Pick one of the provided vocal recordings and convolve it with the original and the modified IRs separately and listen to the results. Do you notice any difference? How would you change the modified IR to change the wet/dry mix?