MUS424:
Signal Processing Techniques for Digital Audio Effects Handout #16
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Homework #6b: Impulse Response Measurement and Analysis [25 points]
Due Date: May 28, 2019

Impulse Response Measurement and Analysis

Submission Instructions

Submit via Canvas. Create **a single compressed file** (`.zip`, `.tar` or `.tar.gz`) containing all your submitted files. Upload the compressed file to the homework submission dropbox. 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 `cavdir_hw1.zip`.

For coding problems (either C++ or Matlab code), submit all the files necessary to compile/run your code, including instructions on how to do it. In case of 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. Illegible homework will not be graded.

Problem 1. [10 points]

In this lab exercise, you will be working in small groups (fewer than 4 people) to measure the acoustics of a room inside CCRMA. We will make a measurement rig available for you to borrow and you will get the pleasure of going through the measurement procedure followed by some processing and analysis after the fact.

After picking your group, choose a space within CCRMA to take acoustical measurements (please make sure that you have some uninterrupted time and reserve the space if necessary). Some good choices include:

- MaxLab stairwell
- CCRMA recording studio (with the absorptive panels open and then closed)
- Main stairwell (with the doors on the first and the second floors closed)
- CCRMA museum (with the doors to the hallways open and then closed)
- CCRMA classroom (with the door to the ballroom closed)
- CCRMA stage

- Roble Field Garage

The impulse response measurement rig we are providing you includes:

1. Mic/speaker stands
2. One or two microphones
3. Speaker
4. Audio interface
5. Power/XLR cables
6. Balloons

Additionally, we are providing some measurement signals for you use. Most of these are signals that you should be able to generate (as part of homework 6a), but we did not want to require you to finish that homework before being able to start on this assignment.

To set up the rig, connect the audio interface to your computer, the microphone(s) and the speaker to the audio interface. There are two microphones provided in the kit, but a single microphone measurement is still sufficient for this lab assignment. You will have to turn on phantom power to the microphone and adjust the speaker and microphone levels to a suitable level (i.e., loud enough but not distorting). You will use your DAW of choice (Audacity is good enough) to play measurement signals out the speaker while simultaneously recording the room response. **Note**, you will also likely need to make sure that any "input monitoring" is turned off in your DAW so your measurements are valid and you don't create feedback.

1(a). [**2 Points**] After setting up the recording rig but before making measurements, explore the space. Clap your hands and make vocalizations. Walk around the space and explore how different parts of the room sound. Now play the Suzanne Vega track out the loudspeaker. Move the loudspeaker to a few positions in the room and listen from a variety of spots. Place the speaker and microphone in places that sounded good to you.

Tell us what room you are measuring, some observations about the sound in the space, and where in the room you decided to place the microphone and speaker for your measurements.

Additionally, **please disclose who you worked with to record the IRs**.

1(b). [**2 Points**] Record a portion of the Suzanne Vega track.

1(c). [**2 Points**] Record the provided sine sweep.

1(d). [**2 Points**] Record the provided the noise burst.

1(e). [2 Points] Pop a balloon from the same location as the microphone and record the response. **Note**, you may need to turn down the preamps of the microphone so you don't clip the signal. Turn in your recordings. Make sure that you use ear plugs. The loudness level of the balloon pop could damage hearing. You can find ear plugs in the kit and in the Max Lab.

Problem 2. [8 Points]

2(a). [2 Points] Convert the sine sweep response into to an impulse response. Plot the spectrogram of the computed impulse responses. You may use the provided `ftgram` function. In addition to taking the signal and sample rate as arguments, it also takes a third parameter which should be either `'rir'` (which is tuned for room impulse response and plots on a log time scale) or `'music'` (which uses a linear time scale). If you type `help ftgram` you will find other parameters (like the resolution of the FFT, hop size, and waveform display) that might also be worth modifying.

2(b). [2 Points] Estimate the SNR of the impulse response.

2(c). [2 Points] Estimate the overall T_{60} of the impulse response.

2(d). [2 Point] Convolve Suzanne Vega track with measured impulse response and compare how it sounds to the Suzanne Vega track recorded in the room. Turn in your audio files, Matlab codes, and plots.

Problem 3. [7 Points]

3(a). [4 Points] We also want to analyze the reverberation of the space in different frequency bands. To do so, you use the following procedure:

- Create a set of 2^{nd}-order Butterworth bandpass filters with octave-wide passbands, each centered around f_c (meaning the passband is between $[f_c/\sqrt{2}, f_c\sqrt{2}]$). Set f_c to be in the range of 62.5Hz to 16kHz at half octave intervals. Check the documentation of the Matlab function `butter` to make sure you're generating the digital version of the filter rather than the analog one.

- Apply the octave band filters to the noise burst recorded in the your space. 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.

- From the filtered signal, estimate the decay time (T_{60}) on a band by band basis by computing the energy envelop with your `energyEnvelope` function, converting the envelope to dB scale, and using least squares to fit a line to the decaying portion of the envelope.

Turn in your code and plots of

- The frequency responses of the filters on a logarithmic frequency axis.
- T_{60} as a function of frequency on a logarithmic frequency scale (using `semilogx`).

3(b). [**3 Points**] Process the balloon pop response using the above process for center frequencies between 62.5Hz and 16kHz spaced in 1/2-octave band centers and compute the T_{60} and initial EQ for each band. From those values, plot the following quantities:

- T_{60} as a function of frequency with a logarithmic frequency scale (using `semilogx`).
- Initial EQ as a function of frequency with a logarithmic frequency scale (using `semilogx`).