EENG580 Activity 1: Acoustic Impulse Responses

03-17 October 2016

Activity summary

Overview: Use a microphone and possibly a speaker to measure acoustic impulse responses of different environments.

Setting: Develop in class, then collect data around campus.

Curricular elements: both tinkering and gaming

Prerequisites: basic familiarity with MATLAB

Topics/concepts covered: impulse response, frequency response

Learning outcomes: After completing this activity, students should be able to:

- define and explain the terms “impulse response” and “frequency response.”
- measure the impulse and frequency responses of an audio environment.
- explain features of the impulse and frequency responses to the geometry of the environment.

Expected time to complete: two 2-hour lab sessions and 4-8 hours of work outside of class

Required hardware/materials: Minimum: a microphone attached to or embedded within a computer, in such a way that the audio input can be queried by MATLAB.

Required instructor interaction: partially supervised, with occasional guidance

Common mistakes/pitfalls: If all students are using different hardware (speakers and computers) it can be difficult for the instructor to help debug problems. It is recommended to purchase enough microphones and speakers to provide one per group. The instructor should verify correct operation of the devices before giving them to students. If possible, the instructor should test the audio recording capability on both PCs and Macs.

Method of assessment: instructor graded, based on final product; plus peer voting on subjective evaluations of the competitions

Contributors: Jenny Hefner and Cody Watson

This work was supported by ONR grant N000141512442, *Contact: andy.klein@wwu.edu and richard.martin@afit.edu.*

1 Getting started

This is a very open-ended activity. Everyone will have a different approach, or a different "answer." This is likely to be a very frustrating exercise at times, but that is ok; the instructor is here to help you, and you should not hesitate to ask questions. A lot of information is intentionally missing from this lab description; you will need to ask questions the complete this lab. The goal of the activities in this course is to encourage a "maker" mindset wherein you feel free to tinker and explore different approaches. We want you to fail, rapidly and frequently, because that is how you identify and correct errors. Your goal is to get comfortable with the idea of rapid prototyping and rapid response.

Pick a lab partner for this activity. You will collaborate on the process, but you will write up individual reports and receive separate grades.

Obtain a speaker and a microphone from the instructor. Unless noted otherwise, the basic audio equipment used in this class will be comparable to the following:

- Microphone: Cyber Acoustics Desktop Unidirectional Microphone (CVL-1064), about $7
- Speakers: AmazonBasics USB Powered Computer Speakers (A100), about $14

Ideally, everyone will use the same type of equipment rather than audio gear embedded in laptops, in order to maintain a level playing field. Plug in your equipment, make sure each device is turned on, and make sure each is set to the default device of its type.

Explore the following MATLAB commands:

- `audiorecorder`
- `record`
- `play`
- `stop`
- `resume`
- `pause`
- `getaudiodata`
- `sound`

The explanation in the help files should be straightforward; the only parameter you will need to choose is the sampling rate `fs`. To assist with this, look up the sampling rate of telephony, MPEG audio, voice over IP (VoIP), and compact discs.

Progress to the point where you can record a snippet of speech and then play it back over the speakers. If you can accomplish these tasks, you have sufficient understanding of the hardware interface to complete the entire activity.

2 Tasks

For the first week of this activity, you are expected to study the following material in advance: discrete time signal notation and building blocks, system properties such as linearity and time invariance, and characterization of a system by its impulse response. Before the second week, you should view the basics of the discrete Fourier transform, and the relationship of a system's impulse response to its frequency response. Videos covering these concepts are available on the course website, and you are encouraged to read additional background material in any of the suggested reference textbooks.

The core task in this assignment is to measure the acoustic impulse response and frequency response of several different environments. You will need to generate an audio impulse and then measure and process the resulting audio signal. To enable this, explore how to address the following issues:

(i) How do you generate an audio impulse? Note that it should be repeatable and impulsive as possible. What is the spectral content of an ideal impulse? Note that you do not have to use the speakers to generate the impulse, it is just one option open to you. How close to "ideal" is the impulse you generate?
(ii) What environmental features will generate interesting effects in the impulse response? What response would you expect to see in free space? What would you expect in a small concrete room?
(iii) If you make use of the speakers, how do you deal with an asynchronous transmitter and receiver?
(iv) How can you generate a "smooth" frequency representation from noisy data? Note that the built-in `FFT` command assumes that the number of frequency samples is equal to the number of time-domain samples that you feed it. What are some different ways you can try to average out the noise? This is probably the trickiest part of the lab.
(v) Does the inherent response of the microphone limit what can be measured?

You will probably complete your initial explorations during the first class session. Between the two in-class sessions, use your time to gather and save some data. In the second in-class session, focus on processing the saved data using multiple approaches, and on interacting with the instructor regarding any difficulties in your approach. Then use some more out-of-class time to take your final data sets and write up your report.

3 Deliverables

You will turn in a report written using the LaTeX word processing system. A template is available on the course webpage. The report should conform to the style guide for IEEE Signal Processing Society conferences, such as ICASSP, ICIP, or GlobalSIP. At a minimum, explain your measurement methodology, your data processing methodology, and your results. Both format and content matter – in particular, use correct grammar and spelling, and revise your text as needed to make sure you are explaining yourself coherently. Include code sparingly, if at all; in general, it is better to include an algorithm in pseudo-code as a figure.

You should strive to always explain why you did what you did, not just what you did. Your results should all be repeatable – maybe not exactly, but comparably. That is, another researcher may not have access to the exact same environment as you or record the exact same realization of random noise, but you want to enable them to follow the exact same process as you. Analysis is also highly encouraged – explain why the results are what they are, not just what they are. For this activity, photos or sketches of the geometry may help with that.

To improve your grade, include a more detailed and coherent explanation of your results, try a more clever or innovative approach, and include more data and analysis. Feel free to diverge somewhat from the stated tasks if you think the situation warrants it. "Out of the box" thinking will always be rewarded.

4 Competitions

The written report constitutes 90% of the grade, and the remaining 10% will be based on competitions. There are three challenges:

- Find an impulse response with a significant coefficient at the longest delay possible, and geometrically show why that coefficient arose in the recording environment. Here, "significant" means that the amplitude is at least 10% of the amplitude of the largest coefficient in the response.

- Find a frequency response with as many nulls as possible and relate it to the geometry of the environment. Here, “nulls” are distinct valleys that dip by a factor of two in amplitude relative to the closest local peaks on both sides.
- Characterize as many unique responses as possible. All “environments” or “acoustic systems” are permissible; be creative.

Competitions will be determined by presenting results to the class, immediately before the start of the next activity. The first two challenges are easy to quantify, but as the third is subjective, the winners will be determined by class vote. The first place group in each category will receive a 10% bonus (for each group member) and the second place group members will each receive 5%; and no individual may receive more than 10% total. Based on typical class sizes, that means about a quarter of you will get 10% and another quarter will get 5%.