EENG580 Activity 4: Acoustic Wireless Communication System

Activity summary

Overview: Design a wireless communication system using audio hardware

Setting: Develop in class, then refine after class (any location).

Curricular elements: both tinkering and gaming

Prerequisites: basic familiarity with MATLAB

Topics/concepts covered: modulation, basis functions, the discrete Fourier transform

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

- Explain how the frequency response of a system and the spectral content of interference affect different communication waveforms.
- Use filters and/or Fourier-based methods to discriminate between different waveforms.
- Evaluate computational complexity of a system and design computationally efficient systems.

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

Required hardware/materials: Minimum: a microphone and a speaker attached to or embedded within a computer, in such a way that MATLAB can query the audio input and send data to the speaker.

Required instructor interaction: partially supervised, with occasional guidance

Common mistakes/pitfalls: If all students are using different hardware it can be difficult for the instructor to help debug problems. It is recommended to purchase enough microphones 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. It may be necessary to turn "noise reduction" on in the microphone device options.

Method of assessment: instructor graded, based on final product

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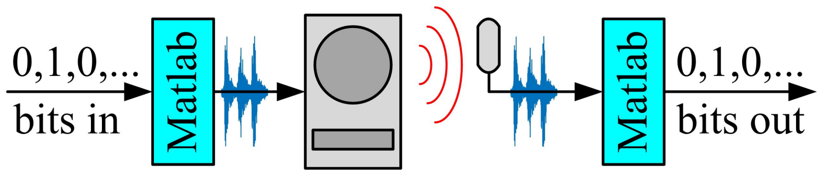

Figure 1: An audio communication system.

1 Introduction

This is a very open-ended lab, probably unlike most labs you have done before. Everyone will have a different approach, or a different "answer". You will design your own end-to-end digital wireless radio. This will require you to think deeply about your current knowledge of signals and apply what you have learned. 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.

This lab will throw you right into the problem of building a digital transmitter and receiver, and force you to immediately confront many of the practical "issues" in the lab before they are presented in the lecture. While potentially frustrating, this will give you a strong appreciation for these issues. In this project, you will send and receive acoustic signals instead of more typical electromagnetic signals used in most wireless communication systems. To send bits, you will emit sound waveforms from a speaker. To receive bits, you will use a microphone to record signals which you will subsequently process to recover the original transmitted bit sequence. While the physical transmission and reception in an acoustic radio are certainly different from an electromagnetic radio, the signal processing principles are the same. You will construct the entire transmitter and the entire receiver in MATLAB by making use of the built-in capabilities that let you play a sound from the speaker and record a sound incident upon the microphone. The commands to play and record a sound will be provided for you.

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; these are the same items you used in "Activity 1: Acoustic Impulse Responses" and "Activity 3: Audio Filtering." If you are comfortable with the operation of the equipment, you may skip to Section **??**; otherwise, work through Section 2 first.

2 Review of the audio hardware

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.

3 Getting started

For the first week of this activity, you are expected to study the following material in advance: sampling, reconstruction, AM/FM communication, and multicarrier communication. Before the second week, you should study the material on downsampling, upsampling, and interpolation. 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 design a MATLAB transmitter, and a corresponding MATLAB receiver so that you can send at least 10 bits of information in 10 seconds or less without any bit errors. For example, if I ask you to transmit the 10-bit sequence 0101001101 (assumed to be unknown by the receiver), the transmitter that you design which will need to generate a signal that will be played through the speaker. In addition, you need to design a receiver which will process the recorded version of the transmitted signal and correctly recover the 10 bits of information. Section 6 will discuss competitions for more advanced designs.

You will ultimately need two computers to demonstrate that your setup works because it would be too easy to accidentally “cheat” if the supposedly unknown bits resided on the same, single computer. For now, though, you can use a single computer (unless extra are available). On one computer (the “transmitter”), plug in the speaker and make sure all of the playback volume levels in Windows are set to the maximum. One another adjacent computer (the “receiver”) plug the microphone and adjust the levels, though the setting is somewhat hidden: Control Panel → Sound → Recording tab; select microphone and click Properties → Levels tab → Set the volume to 100% and the boost to +20.0 dB.

Recall your work in “Activity 1: Acoustic Impulse Responses.” Use your prior code to determine the impulse response and, more importantly, the frequency response of the end-to-end system including the speaker, propagation through the air, and the microphone. Use this to guide your later work; specifically, don’t design waveforms with large amounts of frequency content in regions with low frequency response.

4 Main task

Now, for the main part of the lab: designing an end-to-end wireless transceiver. You need to design an appropriate transmitter, which turns bits into a signal that is played over the speaker. You also need to design a receiver that processes the recorded signal and decodes the bits. Again, this system is depicted in Fig. 1.

Your goal is to design a MATLAB transmitter, and a corresponding MATLAB receiver so that you can send at least 10 bits of information in 10 seconds or less without any bit errors. For example, if I ask you to transmit the 10-bit sequence 0101001101 (assumed to be unknown by the receiver), the transmitter that you design which will need to generate a signal that will be played through the speaker. In addition, you need to design a receiver which will process the recorded version of the transmitted signal and correctly recover the 10 bits of information.

You will need to address the following issues:

(i) What are some pairs of distinct waveforms that you could use to denote “1” and “0”? List as many pairs as you can think of, and evaluate their pros and cons.
(ii) How does the frequency response of the environment affect which waveforms work well or poorly?
(iii) What is the best way to map an input sequence of bits to a single, continuous waveform to be transmitted?
(iv) Your transmitter and receiver will be asynchronous, though you may do your best to manually trigger them at the same time. How will you make your design robust to timing mismatches? How large of a timing error can you handle?
(v) What sources of audio interference are present in the classroom as you design and initially test the system? How will that complicate your design validation procedure?
(vi) What is the most effective and/or most efficient way to decide which bit was received in each portion of the received data stream? Some concepts from filtering may help here.

5 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.

6 Competitions

The written report constitutes 90% of the grade, and the remaining 10% will be based on competitions. Competitions will include the following:

- Maximize the bit rate. That is, reliably transmit as many bits as possible within 10 seconds. The winner will be the group with the most correct bits, but a winning system must receive at least 90%

of the transmitted bits correctly. That prevents you from transmitting 1,000,000 bits and guessing randomly, which would give you about 500,000 correct bits.

- Maximize the distance between the transmitter and receiver while still transmitting at least 10 bits in 10 seconds with zero errors.
- Present an analysis of the computational complexity of your receiver to the class. The winning group will use the fewest number of multiplies (or divisions) per bit, while still transmitting at least 10 bits in 10 seconds with zero errors. You may use as many additions and subtractions and as much memory as you like. Each evaluation of functions like cosines or exponentials count as one multiply.

For the sake of fairness, all groups must use the same hardware for the final competition.

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%.