Physics Lab 13: Sound Science and Musical Mathematics

In addition to helping us figure out triangles, trigonometric functions are very useful in modeling periodic phenomena (phenomena which is cyclical). An intriguing application of periodic functions is to sound and music: music is periodic – the variation in sound pressure vs. time is periodic for those kinds of sound we identify as musical. Today, you will investigate two representations of sound and music, and how sound can be represented visually. In Physics Lab 14, you will continue this investigation.

Getting Started:

a) Obtain a LabQuest 1 (or LabQuest 2), a power supply, and a computer connection cable. You won't need any external sensors – you will be using the internal microphone built right into the LabQuest. Find the microphone on your device (on the LabQuest 1, it is a small circular opening near the top right corner of the unit face, and on the LabQuest 2 it is a more elongated opening on the left hand side, just above the middle).
b) Plug in your headphones, which you will be using as a speaker, and position your equipment so that one side of your headphone can be close to the LabQuest microphone. You might find it convenient to also be able to listen with the other side.
c) Hook up your LabQuest. Launch LoggerPro. Under Experiment: Set up Sensors, choose your interface, and then find and turn on the **Internal Microphone** (this is its own check box; don't look under the list of external sensors). Note the graphs and displays which come up. Under Insert: Additional Graphs, insert an FFT Graph (FFT stands for Fast Fourier Transform.)
d) Under Experiment: Data Collection, note and record the defaults Duration and Sampling Rate. The default settings will allow you to measure acceptable Sound Pressure vs. Time data, though you may need to increase the sampling rate to get cleaner results. To get a good FFT graph, change to a sampling rate of around 5000 samples/second and a data collection time around 0.05 – 0.1 seconds. To get a good FFT graph, you may need a larger sampling rate which might require a shorter collection time; you may need to play around with these settings. This means you will likely need to measure each sound twice, with different data collection settings, to get a good Sound Pressure vs. Time graph and a good FFT graph. This is related to hardware/software limits: you will only be able to get reasonable data for consistent sounds which last a reasonable length of time.

Part I: Pure Tones – Simple Periodic Functions

a) You will begin today's investigation by obtaining Sound Pressure vs. Time and FFT graphs for pure tones generated by a computer. Set the volume on the computer to a comfortable level.
b) Use an Online Tone Generator, available at **http://onlinetonegenerator.com/**. Make sure the volume is at a comfortable level (recommendation: start with volume all the way down and then slowly increase it until you can hear it comfortably). Use your headphones to listen to the 440 Hz tone. Recall that 440 Hz is 440 cycles/second, which means that in 1 second, the tone repeats 440 times. Then, listen set and listen to an 880 Hz tone. The higher frequency tone should correspond to a higher pitch – is that what you observe?
c) Reset to 440 Hz, and move (one end of) your headphones near the microphone on the LabQuest. If needed, set the Data Collection Settings back to their defaults. Zero the sensor (from a drop down menu or just hit Ctrl and 0 at the same time). To collect data, you should always start the sound, then hit Collect while the sound is already playing, and the sound should continue to play even after the data has been collected (you don't want to Collect data while the sound isn't on).
d) Press play for the 440 Hz tone, press Collect (or hit the Space Bar), and once the data is collected, hit stop in the Online Tone Generator.
e) Select the Sound Pressure vs. Time graph. Change the horizontal scaling so that you display about 5 full periods. Highlight at least 3 periods, and then fit the data with a Sine function using Curve Fit. The Curve Fit gives you the best fit parameters A, B, C, and D. We won't use C and D today. A is the vertical stretch or the amplitude of the graph, which in this case corresponds to the loudness of the sound; we won't use it either but at least it is connected to something observable. B is the horizontal stretch, related to the period P (the repeat time) of the graph. The period P is related to the frequency f by $f = 1/P$. You will only use B in this lab.
f) Calculate the frequency f using $f = \frac{B}{2\pi}$. How does this calculated value match up with the frequency you set?
g) Insert an FFT graph using Insert: Additional Graphs: FFT Graph. Adjust your Data Collection Settings so that your Sampling Rate is 5000 samples/second and the Duration is at least 0.05 seconds (there may be a trade-off here so see what works best – you might need to increase the sampling rate and thus decrease the duration). Play the 440 Hz note again and obtain its FFT graph.

h) You should see a single primary peak (there may also be much smaller peaks which are probably an artifact of the computer's sound card or the responsiveness of your headphones). Zoom in horizontally to focus on the main peak. Use the Examine tool to find the peak frequency (the frequency associated with the maximum of the peak). How does the primary frequency from the FFT Graph match your result from the curve fitting?
i) Repeat the data collection (Sound Pressure vs. Time graph and FFT graph) and analysis for an 880 Hz tone.
j) (This part might not work as well given your computer's particular sound card. See what you can do). You can play a 440 Hz tone and an 880 Hz tone at the same time, if you have the Online Tone Generator open in two different tabs in your browser. Do so, obtaining a Sound Pressure vs. Time graph and an FFT graph for the combined 440 Hz and 880 Hz sound. While there is no need to fit a Sine curve to the Sound Pressure vs. Time graph, do note how the graph of the combined sound is similar and different from the sounds it is composed of. Pay particular attention to the FFT, which should now have two main peaks. What are the peak frequencies of the two main peaks?

Part II: Tuning Forks – Pretty Simple Periodic Function

a) In Part I, your data might have been very cleanly periodic, looking like a textbook sine curve for the Sound Pressure vs. Time graph and with a single (or single predominant) peak in the FFT Graph. In this part, you will repeat your measurements for sound from a tuning fork. This should also be periodic, though depending on your tuning fork might be more complex.
b) Obtain a tuning fork. Recall that it is **incorrect** to sound a tuning fork by striking it on a table or similar hard surface. The proper way to sound a tuning fork is to strike it with a rubber mallet, hit it against the ball of your thumb or finger, or hit it on your knee.
c) Return to the default Data Collection settings. Zero the sensor. Sound the tuning fork, hold it near the microphone, and hit Collect. Obtain a good Sound Pressure vs. Time graph. If necessary, increase the Sampling Rate. Recall that depending on your tuning fork, your data might not be as simply periodic as what you obtained in Part I.
d) Change the horizontal scaling so that you display about 5 full periods. Highlight at least 3 periods, and then fit the data with a Sine function using Curve Fit. Use the B value to calculate the frequency f .
e) Find the frequency of the tuning fork (it is usually stamped or engraved on the handle of the fork though if you are using the forks set into a resonance box, you should ask an instructor). How does your measured frequency match the labeled value?
f) Adjust your Data Collection Settings so that your Sampling Rate is 5000 samples/second and the Duration is at least 0.05 seconds (there may be a trade-off here so see what works best). Sound the tuning fork and obtain a good FFT graph. How does the primary frequency from the FFT Graph match your previous result?

Part III: Vowels and Whistles – Complex Periodic Functions

a) In Parts I and II, you obtained data for sound that displayed simple periodic behavior. Most interesting sounds display much more complex periodic behavior. Open the LoggerPro file Trumpet Sound available in the program share under Handouts: Week 8 Lab. You can see that the Sound Pressure vs. Time graph is periodic (it repeats) but is very complex. The FFT graph also shows the complexity of this sound.
b) Following the procedure above, obtain good Sound Pressure vs. Time and FFT Graphs for your voice saying the vowels "E" and "O". Note that you will have to say and hold the vowel sound while collecting data. As before, start and hold the sound, then hit collect, holding the sound constant while the data is collected.
c) Compare your "E" to your "O", especially the FFT graphs for each vowel sound. Is there a clear distinction in the two patterns?
d) Now, compare your "E" FFT graph with your neighbor's "E" FFT graph and similarly for the "O". Are there similarities between your "E" and your neighbor's "E" FFTs?
e) Collect data for the other vowel sounds.
f) If you can't whistle on demand, work with a neighbor who can. Collect data for different notes of whistles. If you and your neighbor can both whistle, compare your data for whistling the same note.

Part IV: Musical Instruments – Complex Periodic Functions

If you brought a musical instrument (or bottle), obtain Sound Pressure vs. Time and FFT graphs for different notes on your instrument. It might be hard to make a note on certain instruments and collect data at the same time; work with an instructor or classmate as needed. If you are using a bottle, you might be able to make different notes by changing how hard you blow across the bottle top. Alternatively, you might be able to make different notes by filling the bottle with water to different heights (say a quarter full, a half full, three quarters full, etc.) and blowing across it for each water height; you might pursue a systematic investigation to see how the FFT graph changes while changing the height of water in the bottle. If available, you might choose to investigate the sounds produced by running a wet finger around the rim of a wine glass.