SCI220 – Foundations of Musical Acoustics
Cogswell Polytechnical College
Fall 2008

Week 1 – Class Notes

The Nature of Sound (MA[1])

Acoustics: the science of sound. The study of the physical nature of sound.

**Pitch:* the sensation of how “high” or “low” a sound is.
**Loudness:* the sensation of strength or weakness of a sound.

Sound entails a disturbance of the air through which it moves and consists, in air, of longitudinal waves that carry energy outward from their source.

Vibration: rapid back-and-forth movement of a single object or a small piece of a larger object.

Wave: disturbance traveling outward in all directions from a vibrating source.

How are the two concepts connected?
The passage of a wave through any region causes the material to vibrate. However, the vibration does not carries the material very far, and after the wave has passed the material returns to it's original position. The material, say air, does not travel, instead it is the signal in it that moves.

A sound wave in air creates two distinct areas:
Compressions: region in which air density and pressure is greater than under normal conditions without the sound wave.
Rarefactions: region in which air density and pressure is lower that under normal conditions.

Compression is created by temporarily moving the air into that region from the adjoining rarefactions on both sides. Some time later the compressed air will expand into a normal state and will become occupied by a rarefaction.
The pattern of air density going outward from the source is that of more and less density.

Waves can be classified depending on the direction of travel into transverse (perpendicular motion with respect to the direction of travel, ex. sinusoidal wave) and longitudinal waves (parallel motion with respect to the direction of travel, ex. a slinky).

---

1 MA – Musical Acoustics. 2nd ed. Donald E. Hall.

Wave composition – basic description:
Crest or peaks: highest point of compression.
Through or valley: lowest point of compression.
Wavelength ( ): distance from crest to crest or valley to valley.

Speed of Sound:

Under *ideal* conditions, at room temperature T = 20˚ C, the speed of air is *v* = 344 m/s or 1130 ft/s (770mi/hr).

All sounds regardless of their pitch will travel through the air at the same speed. With a change of air temperature the speed of sound will also change. This is due to the measure of molecular agitation. If the temperature is higher, the random molecular motions will be faster, thus neighboring molecules will collide more often, and they will pass sound disturbances faster.

Generally, for about 1˚ C increase in temperature there will be a 0.6 m/s speed increase.

$$v_T = 344 + 0.6(T - 200) \text{ m/s}$$

Pressure and Sound Amplitude:

Pressure amplitude is defined as the maximum increase of air pressure (above normal atmospheric pressure) in a sound wave compression.

Force: push or pull of any kind, with total strength measured in Newtons (N). Has both magnitude and direction, by definition is it called a vector. Given by F = ma

Pressure: force per unit area (N/m^2). Given by p = F/s, where s is t he surface area.

Atmosphere: pressure exerted by the surrounding air upon every surface. One atmosphere is equivalent to 10 N/m^2.

The elasticity of air is essential to wave motion since the increase pressure given by every compression pushes outward in all directions on the surrounding air regions where the pressure is lower, moving them aside so that the compressed air regions can re expand.

Waves and Vibrations (MA)

Frequency (f): rate of repetition. For our purposes rate of vibrations. Measured in vibrations per second, cycles per second, or Hertz (Hz).
Period (P): length of time taken for a single vibration to complete a cycle.
Given by P = 1/f

Fundamental quantities of a repetitive wave:
speed, v
wavelength,
frequency, f

Basic relationship: $v = f$

Waveforms
See Pd examples: A06.frequency.pd and A07.fusion.pd

Simple Harmonic Motion
What are the essential requirements for any object to vibrate?
Equilibrium (E): shape or position in which an object is at rest.

Restoring Force: force whose action is always in such a direction as to return an object to an equilibrium position. It is the “stiffness” or “springiness” of a material.

Inertia: tendency for any body to continue in motion or remain at rest.

Amplitude (A): maximum displacement to either side of equilibrium.

Simple Harmonic Motion: sinusoidal motion, such as that of a mass bouncing on the end of an ideal linear spring, or that of a natural mode.

If the restoring force is *linear,* the restoring force is directly proportional to the displacement.

The frequency of a simple oscillation is determined by the strength of the restoring force and by its inertia.
For example, if K is the ideal string stiffness and we want to stretch it y distance we need a pulling force given by $F = Ky$. Then, if a mass M is hanging from the spring it will bounce up and down with a simple harmonic motion and a frequency of
$f = (1/2)\ \sqrt{K/M}$

Simple harmonic motion does not depend on amplitude.

Work, Energy, and Resonance
Work: transfer of energy to an object whenever a force moves through a distance. Measured in joules(J).
$W = FD$

Energy: Capacity for doing work. Includes *kinetic* and *potential energy.* Measured in joules.
Conservation of energy: energy can be transferred from one body to another or it can change from one form to another, but there is no total change of energy.

How does sound carry energy?
The vibrating source does work upon the adjacent air molecules when set in motion. The energy is then passed from neighbor to neighbor, finally reaching your eardrum and pushing it.

The continuous competition between the restoring force and the inertia of an object in any harmonic oscillator is also the interplay between potential and kinetic energy. As the mass moves towards the equilibrium position the restoring force does work on it, this increasing the kinetic energy (KE). This energy is withdrawn from the potential energy (PE) stored in the spring. As the mass moves away from the equilibrium position and slows down, the restoring force is in a opposite direction from its motion. Meaning that the restoring force does negative work on the mass, this reducing its kinetic energy.

This is in the ideal case of course in which there is no energy loss due to friction and heat or sound radiation. In reality, the total oscillation energy gradually decreases due to these factors.

In order to start an object to vibrate we need to deliver energy to the object by exciting it. Either impulsively, delivering a single impulse by plucking or striking the object with an external agent. Or by continuously exciting it by delivering a continuous supply of energy that maintains a constant energy level in the vibrating object. Thus, the continuous energy introduced into the object compensates for energy losses.

Resonance: vibration of large amplitude occurring when a system with a natural vibration mode frequency f_n is acting upon by an alternating driving force with frequency f_0 and f_0 is nearly the same as f_n.

Chapter 1 (FMA[2]):

Assign reading as an intro to the books topic layout.

Chapter 2 (FMA): Impulsive Sounds: Alone and in Sequence

Impulsive sounds: single sound acoustically produced when striking an object or produced electronically. They usually have some sonic characteristics of their sound source (ex. woody, metallic, glassy, etc. sound qualities).

What is the physical nature of any given recognizable sound as it comes through the air to our ears?

How does the mechanical motion of its source give rise to the sound in the air?

In what way was the source set in motion?

What is the nature of perception (how do out ears and nervous system process incoming sounds?

In what way does the human mind produce s distillation and synthesis of those properties of the sound that are in some way interesting or important to it?

2 FMA- Fundamentals of Musical Acoustics. Arthur H. Benade

2.1 Sequence of Impulsive Sounds
Rate: number of units per single unit of time. Ex, taps/second, miles/hour, meters/second.

Repetition rate (tapping rate or tapping frequency): number-of-taps per second

The number giving the tapping rate is the reciprocal of the inter-tap time interval. Example, Inter-tap time of 1/3 second has a repetition rate of 3 taps/second.

Generalizing the concept we can say that Frequency = 1/Period (f = 1/P)

If the time interval between equally spaced impulsive sounds is varied, say sped up, we no longer perceive them as individual sounds but as a new sound or buzz. If sped up even more we will perceive definite pitch.

Depending on the *repetition rate* we can observe the following:

Impulse repetition rate	Perceived sounds
< 20/sec	Separate impulses with slow-fast tempo
20-150/sec	Buzz
> 100/sec	Tone (with progressively higher pitch)

Pitch: 1) Psychological impression of the height of a sound. 2)Note name used to identify a sound within a scale.

2.2 A Scale of Reference Pitches
Perceived sounds need a pitch specification aside from repetition rate specification because, 1) equal alteration of pitch are not directly associated with equal alterations in the repetition rate and 2) some sounds have definite pitch even If they lack a repetition rate or possess several interlaced repetition rates.

We can use the *Equal Temperament scale* (E.T will be described in future chapters) as a set of reference sounds with a definite repetition rate. E.T is exemplified in the keys of a piano (C1, C#1, D1...). We can match the note names from our reference scale to match the pitches produced by our impulsive sound sequences.

For every octave increase the frequency is doubled and likewise for every octave decrease the frequency is halved from its original value.

2.3 Repetition Rates of Rhythmic Patterns
Two separate impulse patterns arranged such that they're close together (drummer's flam) will be perceived as a different (complex) pattern that preserves the original rate.

When two identical sequences of impulses are perfectly interlaced, say one falls exactly at the middle point of the other, a pattern at twice the repetition rate will appear.

When the sequences are slightly “off” we perceive the pattern in an ambiguous manner. We can either hear the sound at the original repetition rate or it can be heard as part of a sequence of impulses at double the original rate.