Questions

1. Suppose you halve the distance to a sound source. What is the increase in intensity (in dB) ?

2. The speed of sound in water is 1500 ms^{-1}.

   (a) What is the maximum interaural time difference (ITD) of an impulse sound, heard by a human under water? Assume a 10 cm head width.

   (b) What is the wavelength of a 20 kHz sound under water?

   (c) Would you expect human sound localization to be better or worse under water versus in air?

3. In the lecture, we considered an example of a "moth impulse response function" which gave two echoes that are separated in time by τ. Suppose that the echos are separated by a distance of 1 cm.

   (a) For which frequencies does constructive interference occur and for which does destructive interference occur?

   (b) What would this imply in practice about the frequency distribution of the sound that arrives at the ear of an observer e.g. a bat? Where would the notches and peaks be in the spectrum?

4. (a) Describe the spectrogram of a porpoise click.

   (b) Consider a porpoise click reflected off the front and back face of the fish, and suppose the fish is much wider than the spatial width of the click. Describe the echo, as heard by the porpoise.

5. Suppose a moth is flying just outside the edge of a forest, and that a bat is flying over a field near the forest. How does the bat's task of detecting the moth differ from the case in which no forest is present. What strategy might the bat adopt for catching the moth in the new situation described here?

Solutions

1. We are comparing cI^2/d^2 with $cI^2/(d/2)^2$. In dB, the difference is

$$10\log_{10}\frac{cI^2/d^2}{I_0^2} - 10\log_{10}\frac{cI^2/(d/2)^2}{I_0^2} = 10\log_{10}2^2$$

which is about 6 (dB).

2. (a)

$$t = \frac{d}{v} = \frac{.1}{1500} = \frac{2}{3}\cdot 10^{-4} \text{ seconds.}$$

(b)

$$\lambda = \frac{v}{\omega} = \frac{1500}{20,000} = 7.5\text{cm}$$

(c) You expect it to be worse. For any incoming direction of sound, the timing differences between the ears are scaled down by a factor of about 4. So, using the expected timing differences for sound in air, the brain would tend to interpret the timing differences as arriving close to the medial plane. (Even if the brain were to adapt, the task would be more difficult because the timing differences that need to be detected and discriminated are smaller.)

The wavelengths in water are also much bigger, which means there is less shadowing by the head and so the level differences would be smaller too.

Next time you are in a swimming pool, close your eyes and tap or scrape the side of the pool with your nail and try to localize the sound. (Do the same experiment now at your desk and note that you are quite good at perceiving where the sound is coming from. When you go to the swimming pool, you'll be terrible at it.)

3. (a) Constructive intereference would occur for sound wavelengths having exactly n cycles per 1 cm. First take the case of 1 cycle per 1 cm. Sound travels at 340 m/s, or $34,000$ cm per sec, so if we had $\lambda = 1$ cycle/cm, then the temporal frequency would be 34 kHz. We would get constructive interference for $\lambda = \frac{1}{n}$ cm also, where n is any positive integer, and so constructive interference occurs at $\omega = 34, 68, 102, ...$ kHz.

Destructive interference would occur when 1 cm is $\frac{\lambda}{2}$, $\frac{3\lambda}{2}$, $\frac{5\lambda}{2}$, etc, that is, $\lambda = 2$ cm, $\frac{2}{3}$ cm, $\frac{2}{5}$ cm, ... $\frac{2}{2n+1}$ cm, 17 kHz, 34+17=51 kHz, etc, i.e. 17, 51, 85, ...

(b) There would be notches (dips in sound loudness) in the spectrum at frequencies $17+34n$ kHz.

4. (a) A porpose click is a modelled as a Gabor. So it has a short duration, and over that time it has a range of frequencies covering about 1/3 octave (as claimed in the lecture). Its Fourier transform over that time extent would be a Gaussian over temporal frequency. So it would be an elongated ellipsoid in the spectrogram, stretched along the frequency axis. The 'stretch' over time vs. frequency would depend on the window used to define each interval of the spectrogram.

(b) If the fish is much wider that the width of the pulse, then the echos off the front and back will not overlap. The two echoes will then be processed as separate events by the auditory system.

Let's try to relate this to auditory filters and spectrogams. For the two echos, constructive and destructive interference would still occur. However, you would see the interference patterns in a spectrogram only if the spectrogram blocks were long enough to include both echos. This would be a narrowband spectrogram. Specifically, you would see the fine frequency resolution, namely the switching between constructive and destructive across frequency.

The interference pattern would not be noticable to the porpoise since the switching would occur several times across the frequencies within each critical band. In terms of spectrograms, the porposes auditory filters correspond to a shorter duration blocks (i.e. shorter impulse response function), that is, the auditory filters correspond to a wideband spectrogram. You get good temporal resolution (to resolve the two echos) but poor frequency resolution (to resolve the interference.)

5. To detect moths, a bat normally sends a constant frequency (CF) sound which is loud and relatively long in duration so that there is as much total energy as possible received in the echo (i.e. to combat internal noise). If the moth were next to a forest, the forest foliage would reflect the sound too and this reflected sound would be very loud relative to the single moth echo. The bat would not be able to distinguish the "signature" pulsing component of the moth echo from the echo from leaves, since the former would be of tiny magnitude and won't be detectable.

   How can the bat solve the problem? First, it can use the echos of the forest to detect the forest itself. Then, once it is near the forest (and hence near the moth), it could alter the flight path so that it flies parallel to the forest (which it would need to do anyhow) and sends its cries parallel to the edge of the forest. This would give it a better chance of avoiding the echos from the leaves.