The Auditory System and Human Sound-Localization Behavior

Exercises Chapter 7

Problem 7-1 Suppose that sound sources are attached to the surface of a sphere with diameter R, with the subject's head in its center (ignore head size). We constrain the azimuth of the sounds to α_0 deg. Show that the range of elevations to which the sound sources are constrained in such a stimulus system is given by

$$\varepsilon = \pm \arcsin \cos \alpha_0$$

Problem 7-2 For frequencies above about 1350 Hz (Eqn. 7.5), the IPD points to multiple azimuth angles. Analyze how the number of potential azimuth angles depends on the tone's frequency.

Problem 7-3 **a)** Show that the cross-correlation between a signal and its delayed version is equal to the delayed autocorrelation of that signal.

b) Calculate explicitly the shape of $\Phi_{LR}(\tau)$.

c) Now adapt the cross-correlation of Eqn. (7.7) in the following way: in Chapter 6 we saw that a phase-locked auditory nerve can represent the half-wave rectified tone of the neuron's best input frequency quite well. Calculate the cross-correlation function for the half-wave rectified tone and its delayed version.

Problem 7-4 Make an educated estimate of the axonal path-length difference needed to encode an azimuth direction of α_0 deg. To that end, first derive (or find information about) the relationship between axonal diameter and signal propagation speed, and values for the relevant parameters. Assume an average axonal diameter of 3 μm.

Problem 7-5 Assuming that the head is acoustically transparent (low frequencies), estimate the intensity difference (in dB) for a sound source at a distance of 0.7 m from the center of the head, at an azimuth angle of 45 deg. Assume that the ears are a positions R=(0.075, 0) (in meters) and L = (-0.075, 0), respectively.

Problem 7-6 Calculate the HRTF when the pinna reflections arise from two different cavities: the helix (a long path) and the conch (a shorter path). See, e.g., Figure 7.13, path 1. Again assume that the pinna walls are perfect reflectors (no attenuation).

Problem 7-7 In this exercise we assume that the reflection is not complete, but filtered and attenuated by a linear filter with impulse response $r(\tau)$. Rewrite Eqn. 7.27 for this situation, and derive an extended expression for the HRTF.

Problem 7-8 Insert Eqn. 7.36 into the definition of the spectral correlation of Eqn. 7.34 to show that

$$C_Y(\varepsilon;\varepsilon_S) = \frac{\sigma_{\hat{H}_S}}{\sigma_{\hat{Y}}} \cdot C\left[\hat{H}_{HRTF}(\Omega;\varepsilon_S), \hat{H}_{HRTF}(\Omega;\varepsilon)\right] + \frac{\sigma_{\hat{X}}}{\sigma_{\hat{Y}}} \cdot C\left[\hat{H}_{HRTF}(\Omega;\varepsilon_S), \hat{X}(\Omega)\right]$$

Thus, under the validity of the prior assumptions on sound sources, X, and HRTFs the perceived elevation, obtained where C_Y reaches its global maximum, will always equal the actual sound-source elevation.

Problem 7-9 The spectral correlation model predicts that if the source spectrum does correlate with a stored HRTF, the perceived elevation will point to the wrong location. Show that it is possible to design a stimulus spectrum such that the perceived sound elevation can point to any elevation, ε*, regardless the actual stimulus elevation.

Problem 7-10 Expand Eqn. 7.45, by incorporating all first-order reflections in the 2D room (i.e., the primary reflections, like paths 1, 2 and 3, shown in Fig. 7.20); if you dare, also incorporate a number of second-order reflections (like path n).