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 $\alpha_0$ 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 $\alpha_0$ 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 at 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

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

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, \( \varepsilon^* \), 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).