A neuronal stereausis model of sound localisation: real-world evaluation

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Introduction

Traditional temporal-based models of sound localisation have relied on extensive networks of delay lines for their operation. An alternative model – stereausis – was previously proposed (Shamma et al., 1989), which instead incorporates the temporal properties intrinsic to the mammalian cochlea into a neural network that performs spatial integration. We present results from a physical realisation of the stereausis model, constructed from biologically-inspired computational elements, and stimulated with both real and artificial stimuli.

Model Comparison

Jeffress Model

Stereausis Model

Most of the temporal-based models are based upon a model originally proposed by Jeffress (1948). In these models, a pair of delay lines, one from each ear, converge upon a neuron. The relative delays in the two lines compensate for a corresponding interaural time difference (ITD). Thus the neuron’s activity will signal a certain azimuthal location. Many such neurons and delay lines, if properly calibrated, produce a topographic map of azimuthal location.

Physical Realisation of Stereausis

The primary components of the system include an analog “silicon cochlea” processor, and a neural-network post-processor implemented on a digital computer.

Silicon Cochlea

Cochlear filtering is performed by silicon cochleae, implemented with analogue VLSI technology (Fragniere et al., 1997). In realising a 25-channel filter bank with a cascade of second-order low-pass filters, the circuit mimics the functional topology of the mammalian cochlea.

Critical features of the cochlea are the steep high-frequency roll-offs of the filters, and the corresponding rapid phase accumulation. This means that a variety of delays will be available within a small portion of tonotopic space.

Shown below are the cochlea outputs for a pure tone (1425 Hz) stimulus. Note that the frequency-channel density and the steepness of the phase functions will together determine the maximum resolution of the ITD computation.

IQR421: Neural Network Simulator

The stereausis map is produced by a network of model integrate-and-fire neurons. The network model is implemented in real time via the software package IQR421, produced in house. A first cell group performs the cross-channel integration, while a second group integrates over diagonal-shaped regions of the first group.

System Performance

The stereausis system was tested using two types of stimuli. “Ideal” stimuli were produced with function generators and delivered electrically to the cochlear inputs. “Real” stimuli were delivered acoustically and sensed with microphones.

Real Stimulus

The same stimuli delivered in the ideal case were delivered acoustically. In this case, different azimuthal locations of the speaker produce different ITDs (and IPDs). Although the system is affected by the characteristics of the speaker, the room, and the microphone, sound-source location is still easily read from the cell-group activity.

Conclusion

This operational approach makes explicit the relationships between the properties of model components and the realistic performance of the complete system. Our results have demonstrated that a neuronal model of stereausis is able to reliably detect the location of both synthetic and real sound sources.

References