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Study on Sound Localization using Auditory Function Model

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Sound localization is an auditory function to detect of sound source location using the interaural time difference(ITD) and the interaural level difference(ILD) between ears at which the sound waves arrive. In this study, a function model of the auditory sound localization based on the interaural time difference(ITD) is presented.

Sound waves arriving at ears are decomposed into their frequency components and are changed into impulse trains by the auditory periphery. The impulse trains keep timing information in itselves because auditory nerves tend to fire at a certain phase of stimuli. The system for detecting ITDs exists in medial superior olive(MSO), where the nerves coming from left and right ears cross each other. The Jeffress model is one of model circuits for the detection. This model has been approved because of simple theory and structual analogy between the model and tissues in MSO. At the beginning in this study, the Jeffress model is implemented computationally to examine its mechanism and to improve.

The Jeffress model is represented as a circuit which consists of some coincidence detectors and two nerve fibers from left and right ears. The detectors fire only when impulse trains coming from both sides through nerve fibers arrive simultaneously. Thus the model can caliculate ITDs with correlation between impulse trains coming from both sides(Figure 1).

When a sound source is placed in front of the head, arrival times are equal on the left and right pathways, because the times that sound wave comes to ears and impulse trains come to the circuit are equal. Then, the middle detector in the circuit responds most strongly. The position of the responding detector varies as a sound source moves.

Auditory nerve fibers do not always fire at a certain phase of stimuli. Impulses fluctuate temporally and it is difficult to detect ITDs with the correlation between those impulses.

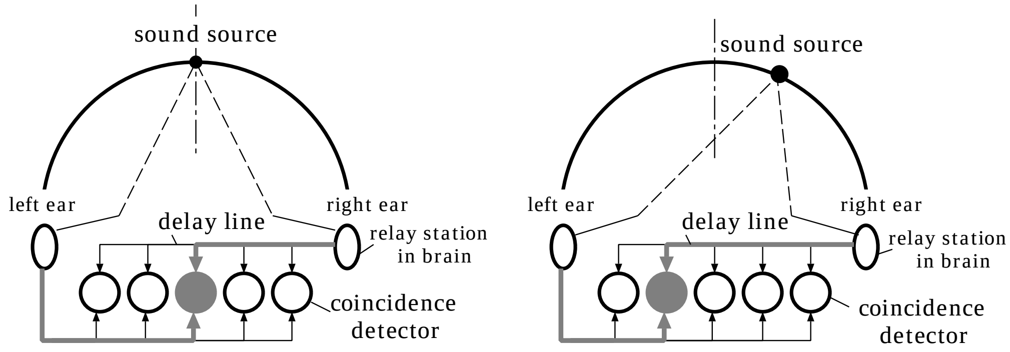

Figure 1: Jeffress model

Figure 2 shows the period histogram of impulse trains with large fluctuation and the output from the circuit with correlation between impulses. The ITD is not clear.

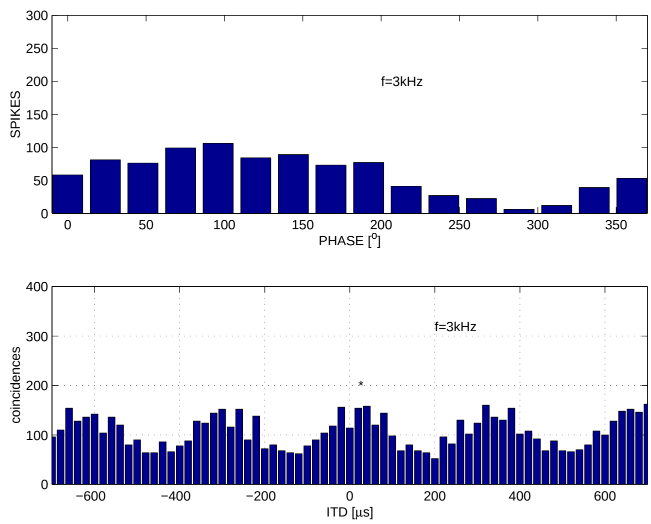

Figure 2: period histogram and the output

Therefore, in this study, the time length and the amplitude of impulses in the circuit are modified into a reasonable shape like a sawtooth wave, to reduce errors of the detection against fluctuation of impulse trains. Figure 3 shows the histogram of the same impulse trains as Figure 2 and the output from the circuit with sawtooth waves. The peak shows the correct ITD clearly.

The model has another problem, related to phase ambiguity that detectors in the circuit respond to more than one ITD, as represented $\Delta t + nT$(n is an integer. T is a period.) when the actual ITD is Δt. To solve the problem of phase ambiguity, the circuits

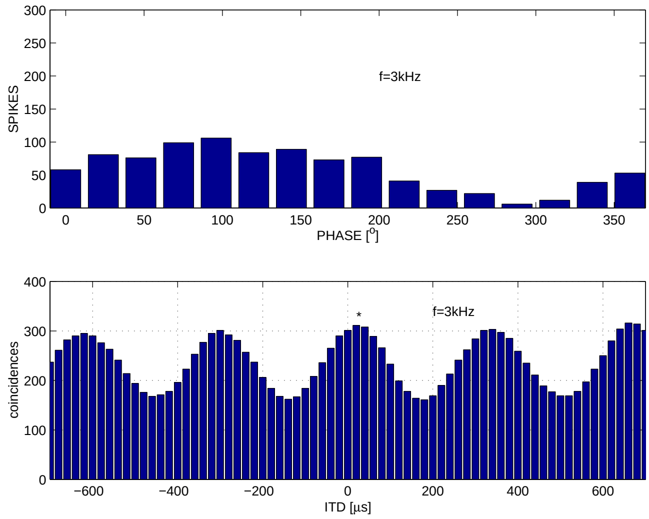

Figure 3: period histogram and the output

are arranged in each frequincy band and the detectors in the circuits are grouped with the same ITD. The most firing group indicates the actual ITD(Figure 4). In fact, it is found that ITD detectors in organisms are arranged systematically along frequency axis.

The model can be improved with the physiological knowledge. However, the simple mechanism to detect the correlation of stimuli from ears, like this model, can not work well under real environments with noise from some sources, like orgnisms do.

To investigate these issues in more detail, signal representations in orgnisms, such as nervous impulse or synaptic transmission, are modeled computationally according to physiological knowledge. For example, an impulse is a deviation of membrane potential called 'action potential' with certain time duration. Additionally, synaptic transmissions extend the width of action potentials. Then, timing information may become obscure. These signals are applied to the coincidence detector circuits of ITD in the model. The results of the simulation using a coincidence detector circuit show that firings of one coincidence detection spread over the circuits, in response to just one correlation (Figure 5). Thus, it is difficult to determine the actual ITD using one coincidence detector circuit.

To determine ITD with more accuracy and calculate it more efficiently, selecting by many thresholds and inhibition are assumed. Since the coincidence detector indicating the actual ITD tends to fire earlier than others, the first firing event at the actual ITD excits its own postsynaptic neurons and inhibits other ones(Figure 6). Consequently, the model with inhibition can improve accuracy to detect ITDs(Figure 7).

In conclusion, nervous impulses and synaptic transmission from left and right ears in MSO are modeled computationally and are applied to a past coincidence detecotor circuit model to detect ITD. The results show that the past model is not able to detect actual ITD independently. Then, the selection by many thresholds and the inhibition are modeled to improve detection accuracy of ITD.

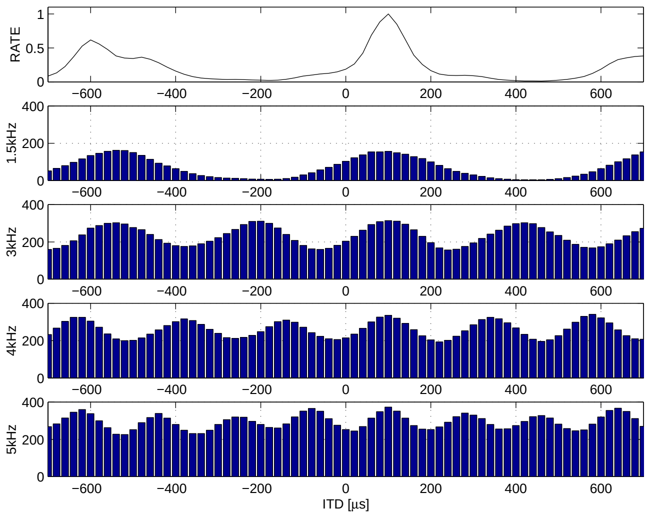

Figure 4: solution for phase ambiguity

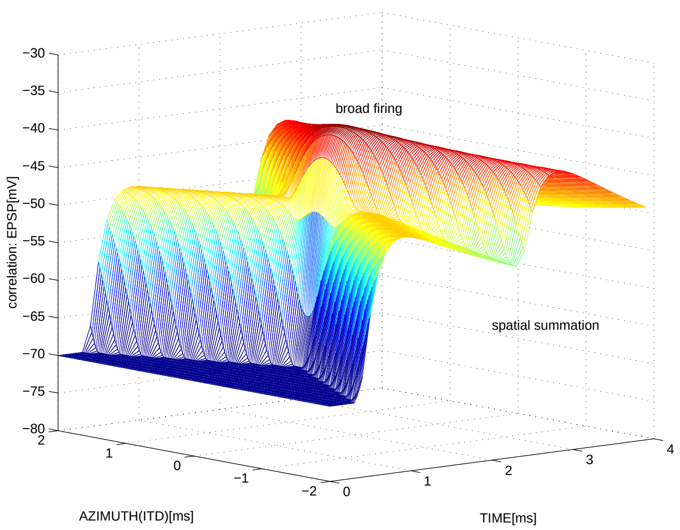

Figure 5: spatial summation in the circuits

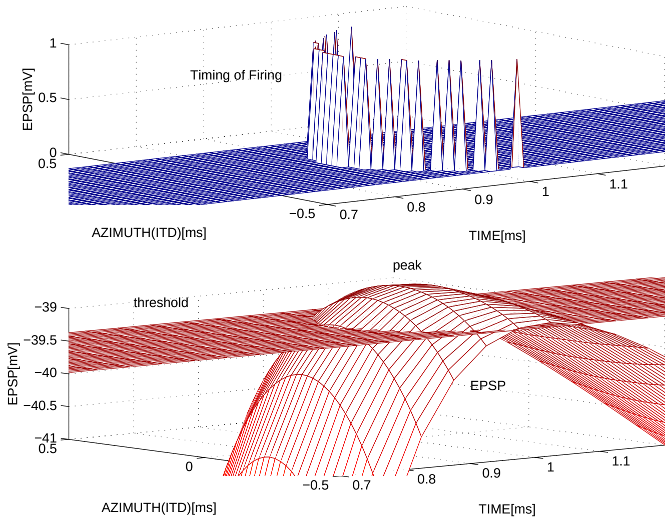

Figure 6: the difference in the timing of firing

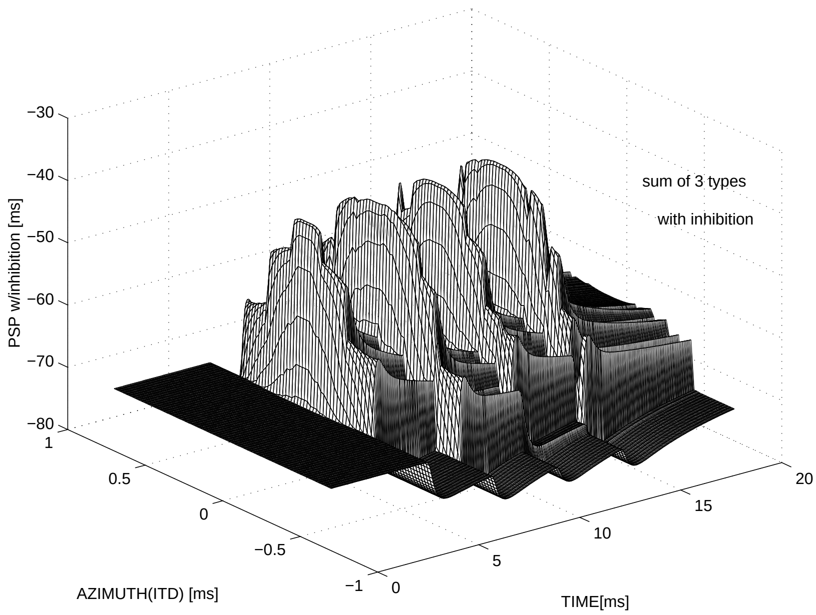

Figure 7: psp with inhibition