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Sensory Information Processing+

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1. Introduction

Three major acceptors of information in man are visual, auditory and tactile senses. Their physiological and psychological researches are very important for the design of artificial image and auditory processings, in addition to the design of sensory aids for the disabled.

We have been working to investigate sensory processing functions in man and animals by psycho-physical techniques and their results were effectively applied to the developments of an ultrasonic mobility and and a voice typewriter for the blind, a tactual vocoder for the deaf and basic methods of image processings. We have been performing the follow-up studies in use of these instruments for the disabled. Their limitation of information acceptance via different sensory route, such as visual information by auditory or tactile sense and auditory information by visual or tactile sense, suggested us many important hints for the design of signal processings.

In this paper, especially, temporal and spatial characteristics and feature extraction in sensory information processing will be analyzed by practical examples and basic problems of effective signal processing will be discussed.

2. Psychophysical Evaluation Technique of Masking

Among many techniques of measurement, the most frequently used one was masking for the evaluation of sensations in our studies. This technique consists of two sources of stimulating energy. These are a masker and

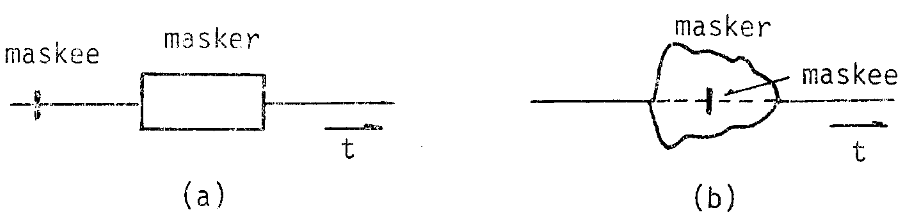

Fig. 1. Two types of masking measurement. (a) for over-all measurement including backward and forward masking, (b) for the evaluation of sensation with different pattern of stimulation

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maskee. The former is the object of evaluation and the latter is the signal to measure sensory effect or masking of the masker. Duration of maskee must be short enough so that it is recognized as a pulse modulated by a certain clearly recognizable pattern. Figure 1 shows two different methods of masking measurement in our experiments. For the evaluation of auditory sense, we usually used the maskee of 5 msec duration with modulation frequency of about 600~5,000 Hz sinusoidal wave.

Changing the amplitude of maskee, sensory threshold level was found and it was plotted against relative time difference between maskee and masker in case of (a) in Fig. 1 or against modulation frequency of maskee in case of (b). For tactile or visual senses, the duration and modulation of maskee can be prepared with suitable modification.

3. Psychophysical Technique for the Measurement of Recognition Time Difference

Another important technique used in our experiments is a psychophysical method of measurement of recognition time difference among visual, auditory and tactile senses. Using this newly developed technique at our Laboratory, two different sensory systems can be compared with respect to recognition time. Figure 2 shows basic principle of our method. Two different kinds of impulsive stimuli are produced with randomly changing time difference of delta t. One stimulus may be sudden color change for visual sense and the other may be click sound for auditory sense. The subject in Fig. 2 is asked to indicate when two different kinds of stimuli are recognized simultaneously among randomly changing delta t. Then, actual time difference in this case may be defined as the recognition time difference, though absolute recognition time is unknown. We used auditory stimulus of a clicksound impulse, an impulsive vibration applied to a finger tip for tactile sense and a visual stimulus of sudden color change from green to red in our experiments.

4. Comparizon of Visual, Auditory and Tactile Senses

For any information processings, major factors are (1) amount of information acceptable per second, (2) frequency characteristics, (3) dynamic range and (4) recognition time. The amount of information acceptable per second is the most difficult object to estimate. Summerizing psychological and psychophysical estimation, it is considered to be: 10^6 bits per second for visual sense, 10^4 for auditory sense and 10^2 for tactile sense. Frequency characteristics at stable and moderate intensity may be defined by flicker fusion

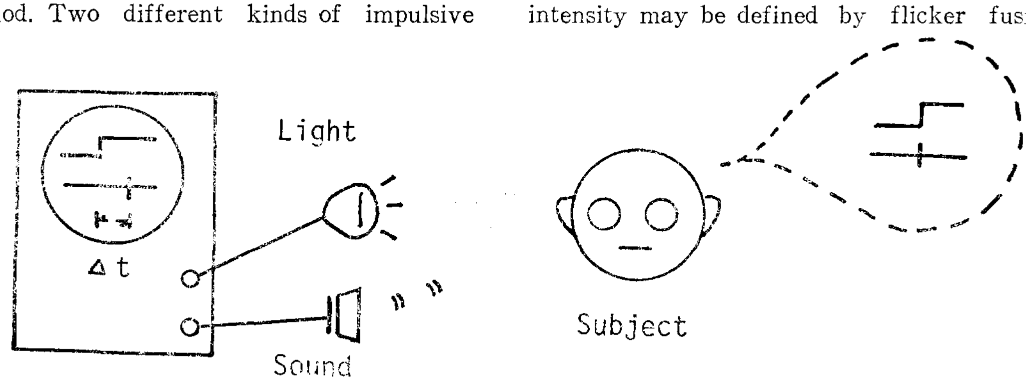

Fig. 2. Measurement of recognition time difference

frequency for visual sense. For black and white images, visual dynamic characteristics is up to 25 Hz. However, for colored images, it must be estimated about 7 Hz less than that of former case, as color critical fusion frequency is about 7 Hz less than fricker fusion frequency of same brightness. For auditory sense, audible range of sound frequency may be the most reliable data to define frequency characteristics. Practically, it may be 100~18,000 Hz. For tactile sense, it is up to 300 Hz. Acceptable dynamic range of intensity is subject to many factors. However, from practical point of view, it may be esti mated as 100 dB for visual and auditory senses and 20 dB for tactile sense.

There is no way to measure recognition time which is time required from insidence of energy to cognition in central nervous system However, the recognition time difference can be measured by the method mensioned above.

We tried to investigate the time needed for processing in sensory nervous systems and sensory areas of brain cortex. It was found that comparing visual, auditory and tactile senses, recognition time of visual sense needed 30 msec longer than that of other senses in addition to the unstability of recognition time. On the other hand, tactile sense was found most stable and almost independent of stimulating energy. There was almost no difference between recognition time of auditory and tactile senses provided that stimulating level was sufficiently high. For weaker stimulation visual sense needed much longer time when brightness was less than 15 Hz in terms of critical fusion frequency, auditory sense needed more time when stimulating sound level was less than 5 dB, while tactile sense was found independent of stimulation level. The fact that visual sense has the highest capacity of information acceptance nevertheless its slower recognition time and unstability may be explained as visual signal processing mainly depends on parallel operation, while auditory sense depends on sequential processing.

These different characteristics of sensory systems are important factor for the design of human engineering aspects of image processing, prostheses, sensory aids and other industrial products such as motor car and highway traffic system.

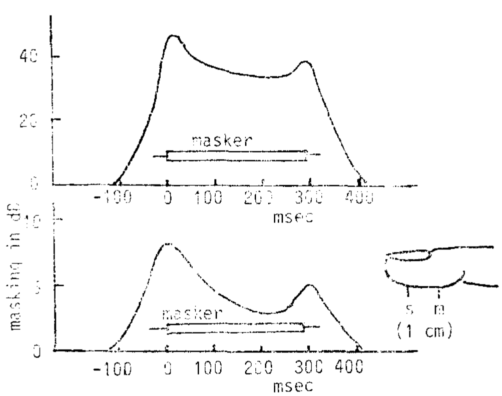

Fig 3. Auditory and tactile masking characteristics

5. Sensory Masking Characteristics of Auditory and Tactile Senses in Man

Fig. 3 shows representative examples of auditory and tactile senses measured by first method shown in Fig. 1 (a). When auditory stimulus of white noise, 36 dB, lasting 300 msec was applied, a backward masking of about 100 msec was found with a peak at onset of masker. During continual stimultion of masker, the masking kept almost constant level. It was followed by a forward masking lasting about 100 msec. On the other hand, when tactile stimulus of 250 Hz, 12 dB was applied at point m and its masking effect was measured at point s, 1 cm distal from m, it showed basically same tendency of masking but with sharp decay of masking during constant stimulation of masker.

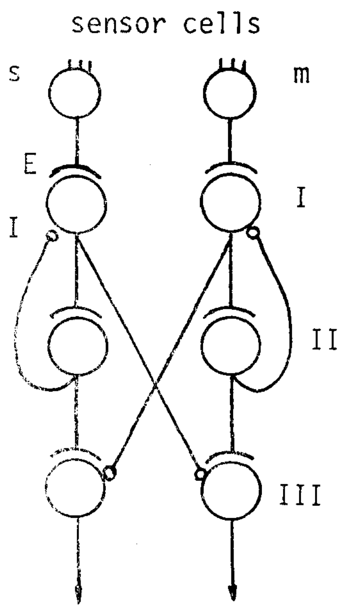

Fig. 4. Nervous network model of masking
E: excitatory synapse
I: inhibitory synapse
s: maskee
m: masker

There were some interesting facts about this experimental results. One was the phenomena of backward masking. It seemed to appear prior to the onset of masker which was apparently discrepant. The other was the decay during continual stimulation of masker. These two problems were explained by a model of sensory nervous network as shown in Fig. 4. It may be possible that the effect of masker interfere the maskee earlier than the signal arrives at the third neuron (Ⅲ) by inhibitory synaptic connection between Ⅰ and Ⅲ layers in a way of cross modulation. This short-circuit connection is anatomically proved in auditory nervous system. The second problem may be explained by self-inhibitory connection or Renshaw connection in a serial route of nervous network.

6. Bionic Modeling of Animal Sensory Systems

Sensory systems of human being are not always superior than those of animals. A dolphin can find any obstacle or his food even in opaque water or at night without light. A bat can find small flying insects in dark. We tried to imitate their ultrasonic sensing system for the design of pattern recognition aids for the blind. A bionic model of animal sensing systems may be applicable for the design of auxiliary aids to accept a signal out of range of normal sensation. For these reasons we are investigating ultrasonic recognition system of pattern in bat and trying to find any way to design their bionic models.

We selected two kinds of bat: one was a small size FM bat, the other was a medium size CF-FM bat. Frequency modulated (FM) signal of the former was such that it started with the frequency of about 90 kHz ended at about 40 kHz within about 1.5msec The other one, CF-FM bat produced 34 kHz constant frequency (CF) for about 10 msec followed by a down sweep FM down to 25 kHz within about 1.5 msec. We put these bats in a He-O_2 mixture with the sound propagation velocity of 520 m/sec and found that production of ultrasonic signal did not change in FM bat, but in CF-FM bat, its frequency was exactly doubled. We concluded this phenomenon as the former produced his ultrasonic signal by tapping his teeth and opening his mouth and the latter produced by ultrasonic vibration with the resonant air cavity of his nasal tract closing his mouth. It was also understood that cognition of echo from an ob ject was performed by comparizon of echo signal and tranmitted wave with the help of short term memory. It was also clear that distance estimation was not performed by required time of reflection but by his binaural estimation of distance, as our FM bat had not any trouble in avoiding obstacles in He-O_2 environment. In case of CF-FM bat, he could not move at all in the atmosphere with accelerated sound velocity. It seemed that he could not process echo from object with doubled frequency, though we could not prove if he could hear his ultrasonic signal of 68 kHz.

This experimental data was then applied to design an ultrasonic eye glass for a mobility aid for the blind by bionic modeling. The similar procedure may be useful for the design of robot sensors.

Another example of our experiment was the study of mimic voice perception by the mynah bird.We found a well trained and his tutor and recorded his mimic voice and his tutor's voice and compared with respect to their formant structures. It was a dramatic experiment. When we analyzed both voices, we found quite different formant structure. The mimic voice of mynah composed of much higher frequency formant compared to the same voice of his tutor. However, its pitch was just the same in two voices, including fluctuation of frequency which characterize speaker's personality. Experimental findings of this fact lead us to analyze auditory sensation of hair cells on basilar membrane in cochlea. We postulated that perception of lower frequency sound could be produced by frequency difference of higher frequency sounds. Then this postulation was proved experimentally with masking measurement of a hard-to-hear subject with −70 dB hearing loss at about 700 Hz by applying 3 kHz and 2.7 KHz. We could obtain distinct rise of masking at 700 Hz while with pure sinusoidal wave of 700 Hz, his hearing loss was −70 dB. We planned to apply this result to the design of a hearing aid and also physiological explanation of perception of harmonics.

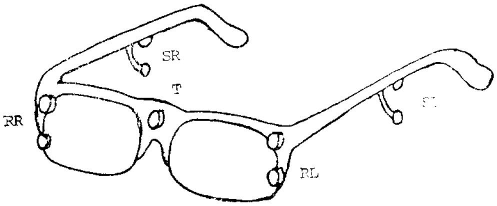

Fig. 5. 3-D ultrasonic glasses for the blind.

7. Ultrasonic Mobility Aid for the Blind A Bionic Application of Bat's Sounding

We designed a three dimansional ultrasonic mobility aid for the blind with the functions of (1) finding an obstackle standing on walking surface, (2) an obstackle at the height of head or chest and (3) a dip such as edge of a platform or down staircase. It consisted of one ultrasonic transmitter, two pairs of receiving transducers and two pairs of small speakers. These were mounted on a glass frame as shown in Fig. 5. The transmitter emitted down sweep FM ultrasonic wave with the center frequency of 40 kHz and modulation width of 1 kHz, or without FM, with the duty ratio of 1 : 2 and frequency of 1 Hz. Its angle of emission was about 60 degrees. Any reflected signal within the range of about 6 meters could be received by two pairs of receiving transducers and then converted into audible sound by a heterodyne detector with the local oscillator of 39 kHz. Their output was presented before each pinna by vertically arranged speakers of SR and

SL. Receiving angle was also 60 degrees. In this case, direction of obstackle was detected by sound locating function of audito sensory system. A concave obstacle was differentiated from convex one by tonal difference of sound. It was not so accurate to estimate the distance between subject and obstackle. This inaccuracy might be caused by poor function of pinna in man.

A simplified version of this mobility aid was made with two receivers at left and right. It is now under test for practical usefullness at some of blind schools.

8. Basic Characteristics of Human Sensory Systems

Though sensory systems in man differ each other with respects of their structure and function, there are some common basic characteritics among visual, auditory and tactile senses. Such common nature may be produced by general rules of neural network construction. Frequent connections in sensory neural system are (1) series excitatory connections, (2) lateral inhibitory connections, (3) self inhibitory feedbacks and (4) mutual inhibiory feed-forwards. On the other hand, there is no excitatory or positive feedback which may cause oscillation.

Fig. 6 shows spatial (a) and temporal (b) sensory characteritics of tactile sense. These characteristics are basically observed in visual and auditory senses too, though their numerical values differ. We posturated that these functions are sum of inhibitory and additive processes. When a finger-tip is stimulated by a vibrator with small point, it causes a summation area of circle and a inhibitory area beyond the summation area. Actual characteristics of this response is the sum of summation and inhibitory components. When we observe the time sequence of this stimulation we find backward and forward masking with a response peak in between as shown in Fig. 6b. In case of auditory sense, existence of critical band may be explained by spatial response of hair cells on basilar membrane. A bionic circuit of lateral inhibition was designed at our laboratory for feature extraction by a bandpass filter bank. Figure 7 shows an element for one channel of which ouptut is

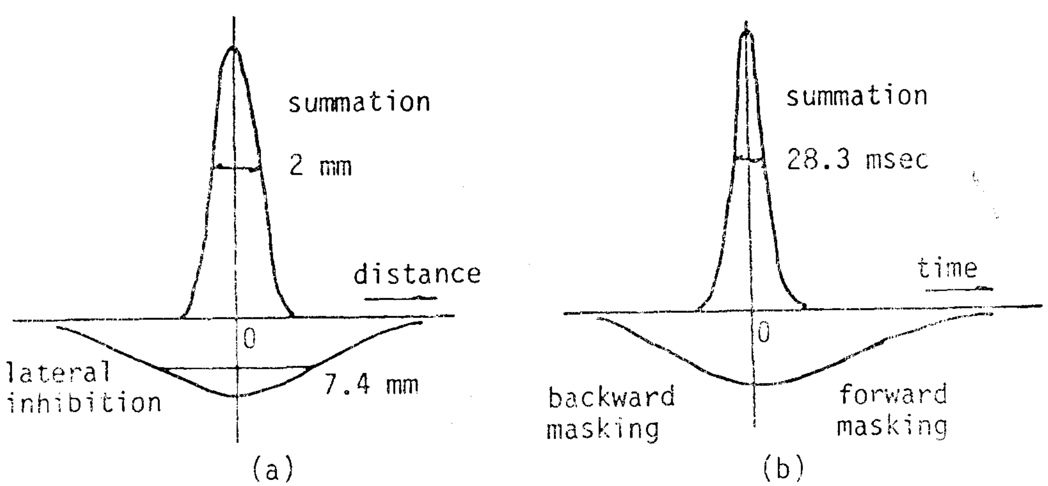

Fig. 6. Spatial and temporal sensory characteristicsof tactile sense at a finger-tip

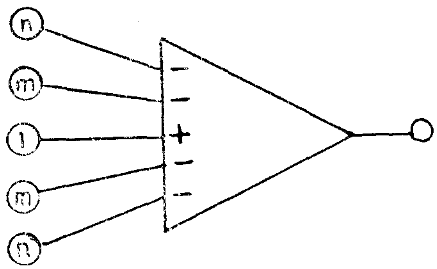

Fig. 7. Lateral inhibitory bionic circuit

connected to additive terminal. The outputs of consecutive channels are connected via weighting attenuators to subtractive terminals of operational amplifier.

9. Conclusion

The sensory signal processing is a nonlinar procedure of neural netwoorks. In this paper, some of its gross view were reviewed by psychophysical data. However, what we need urgently are a mathematical tool to describe nonlinear processing of neural network and development of neural bionic elements useful to construct nonlinear processing circuits.