A PROPOSAL OF PARALLEL MODEL IN THE HUMAN BINOCULAR VISION

Jing-Long WU[1] and Yoshikazu NISHIKAWA[2]

[1] Department of Mechanical Engineering, Faculty of Engineering, Yamaguchi University

[2] Faculty of Information Sciences, Osaka Inst. of Technology

Abstract: The human binocular visual system has been evolving for long time and has attained very high performance as a sensory organ. If the mechanism of binocular vision is elucidated, the findings will contribute to technology of visual sensory system, robot vision etc. In the previous monocular vision studies, a wealth of physiological evidence has demonstrated that the retinal image is represented in the cortex of several different spatial scales ranging from low spatial frequency to high spatial frequency. Furthermore, in our recent psychological measurements, the results suggested that in the monocular vision the chromatic and the achromatic channels have parallel structures. In this paper, a parallel model of the binocular vision system is proposed. It is based on the physiological knowledge and the results of our previous studies on monocular vision.

Key Words: *human visual system, parallel structure, monocular vision, binocular vision, spatial characteristics.*

1. INTRODUCTION

The human binocular visual system has been evolving for long time and has attained very high performance as a sensory organ. If the mechanism of binocular vision is elucidated, the findings will contribute to technology of visual sensory systems, robot vision etc. In the monocular vision studies, a wealth of psychological and physiological evidence has demonstrated that the retinal image is represented in the cortex of several different spatial scales ranging from low spatial frequency to high spatial frequency [1]~[4]. In the Graham and Nachmias's study [3], the contrast thresholds are measured for gratings containing two superimposed sinusoidal components. The frequency of one component is always three times larger than that of the other, but the phase between components and the ratio of their contrasts took on several values. The results suggest that the visual information is processed by multiple-channels. The existence of separate channels (having band-pass characteristics with different optimum spatial frequencies) in the visual system has been shown neurophysiologically. By studying the responses of retinal ganglion cells of the cat to sine-wave gratings, Enroth-Cugell and Robson [5] have shown that contrast-sensitivity characteristic of band-pass type is already established at the level of retinal ganglion cell.

Furthermore, in our recent psychological measurements, the results suggest that in the monocular vision the chromatic and the achromatic channels have parallel structures. In this paper, a parallel model of the binocular vision system is proposed. It is based on the physiological knowledge and the results of our previous studies on monocular vision.

2. RELATED RESEARCH

The researches of binocular vision have a long history. Already by the sixteenth century the astronomer Johannes Kepler had proposed a scientific explanation for stereoscopic depth perception that is still able to generate lively controversy today. Perhaps the most influential development in binocular vision psychophysics during the last 30 years was the introduction by Julesz of the static and dynamic random-dot techniques for isolating visual processing that occurs after convergence of signals from the left and right eyes. As an example of depth information from the disparity [6] is shown in Fig. 1. In this figure, the depth information is added to random-dot patterns by a horizontal shift of the dots in the regions to be seen in depth. To create a raised central square, for example, dots are shifted to the right in the left image and to the left in the right image as seen in the top figures in Fig. 1. To create a depressed surface, dots are shifted to the left in the left image and to the right in the right image as seen in the bottom figures in Fig. 1.

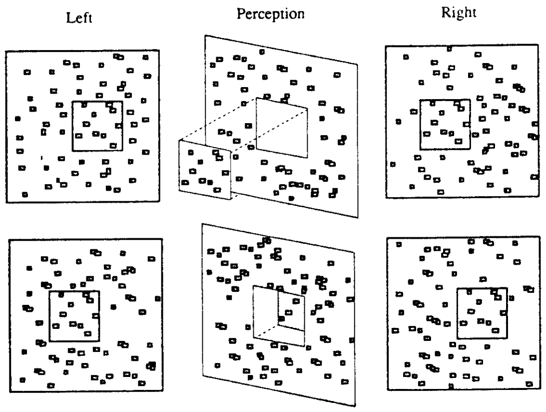

Fig. 1 Depth information from the disparity

In the previous studies on binocular vision, Julesz's difference field model [6], spring-coupled magnetic dipole model [7] and Marr & Poggio's cooperative algorithm [8][9] are known to many peoples.

The binocular fusion of two different faces results [10] in a curious blending of the two, often with a distinct improvement in the facial features. The mirrors are arranged so that the observer's left eye sees a face on the left and his right eye sees the face on the right. The faces blend into one in a most remarkable manner, that is, it produces in the case of ladies portraits, in every instance, a decided improvement in beauty. The point we want to make here is that binocular fusion reveals some critical faculty in the visual system that is capable of making decisions of accepting or rejecting information, apparently on aesthetic grounds. In the recent study, Wilson et al. have suggested that the range of binocular fusion on fine spatial scales (high spatial frequency) is constrained by the coarse spatial scales (low spatial frequency) [25].

3. PHYSIOLOGICAL EVIDENCE

It is known that as physiological knowledge [11]~[14], the receptive fields of the cell are different. Hubel and Wiesel[11] have measured the field dimensions for 112 cells (See Fig. 2).

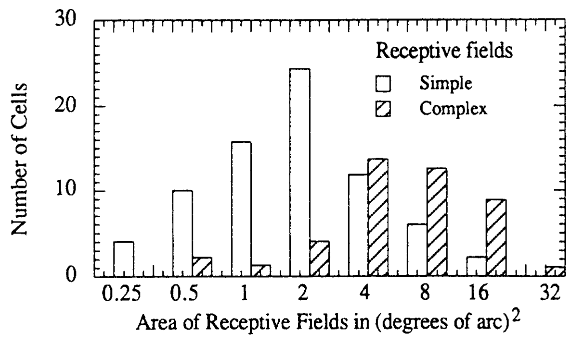

Fig. 2 Distribution of 119 cells in the visual cortex with respect to the approximate are of their receptive fields.

In Fig. 2, the distribution of cells according to the field area is given separately for simple and complex fields. The white and shaded columns indicate cells with simple and complex fields, respectively. The abscissa shows the area of receptive fields. The ordinate shows the number of cells. Hubel and Wiesel[11] have also shown that binocular interaction and ocular dominance in the visual cortex (See Fig. 3). That is, the structure of receptive fields in the visual cortex has spatial selectivities. The spatial structure may be not only useful for monocular information processing, but also useful for binocular information processing. The physiological structure suggests that the human information is processed by a parallel ways.

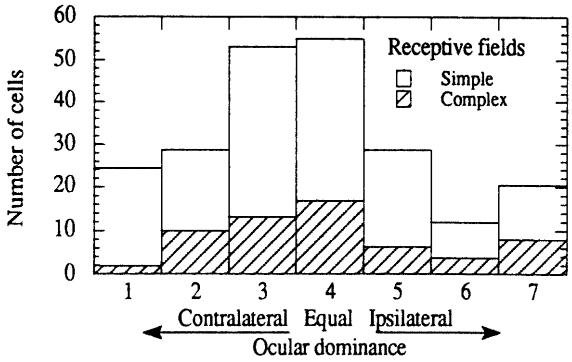

Fig. 3 Distribution of 223 cells from the visual cortex, according to ocular dominance. Histogram includes both cells with simple fields and complex fields. The shaded region shows the distribution of cells with complex receptive fields. Cells of group 1 were driven only by the contralateral eye; for cells of group 2 there was marked dominance of the contralateral eye, for group 3, slight dominance. For cells in group 4 there was no obvious difference between the two eyes. In group 5 the ipsilateral eye dominated slightly, in group 6, markedly; and in group 7 the cells were driven only by the ipsilateral eye.

4. PARALLEL STRUCTURE IN MONOCULAR VISION

It has often been claimed that the human monocular visual system involves three channels in early stages of the processing [15]~[19]. The three channels are termed a red-green channel, a yellow-blue channel, and an achromatic channel, respectively. It is supposed that the former two channels deal with chromatic information and contribute to color perception, while the third one is specialized for achromatic information processing and serves brightness perception. In previous psychological investigations, the achromatic channel has been considered as a single one that can be presented by a linear sum of the spectral sensitivities of two sorts of photoreceptor in the retina, i.e., the M and the L cones [16][20][21] . However, in our recent measurements[22][23], the results suggest that the chromatic and the achromatic channels have parallel structures.

4.1 A Parallel Model of the Achromatic Channel

In order to determine the mechanism of the achromatic channel, the spatial characteristics and the spectral sensitivities have been measured by our recent study [22]. The results suggest that the achromatic information is processed by several subsystems in parallel. Based on the experimental results, a parallel model of the achromatic channel has been proposed as shown in Fig. 4. The parallel model has three subsystems with five stages.

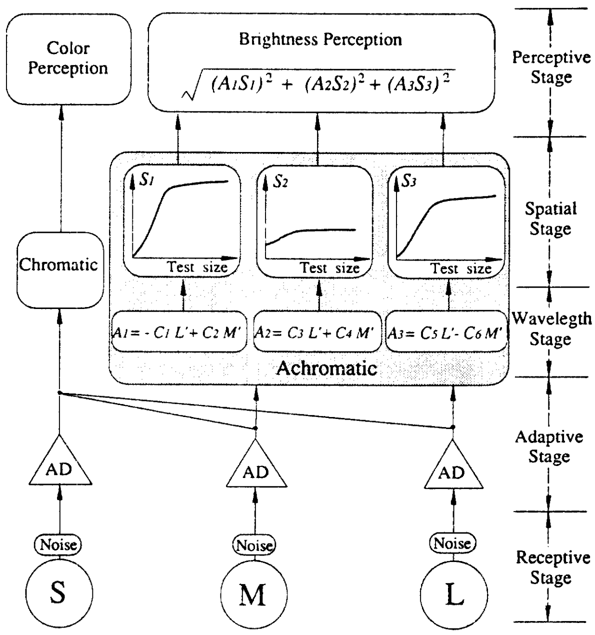

Fig. 4 A parallel model of the achromatic channel (Wu, Kita & Nishikawa, 1995)

(1) *Receptive Stage*

The input information is caught by the receptor *S*, *M* and *L* cones.

(2) *Adaptive Stage*

The adaptive mechanism has a property that the receptor activity is reduced by an increasing factor as the receptor response increases.

(3) *Wavelength Stage*

In three subsystems, the spectral sensitivity characteristics of the wavelength mechanisms A_1, A_2 and A_3 have their peaks at short-, middle- and long-wavelength ranges, respectively.

(4) *Spatial Stage*

The mechanisms S_1, S_2 and S_3 have different dependencies on the test size. When the test size is changed from small to large, S_1 and S_3 change remarkably, while S_2 does not.

(5) *Perceptive Stage*

In the final stage, the achromatic perception is calculated by three subsystems. They have different spatial and spectral characteristics.

4.2 A Parallel Model of the Chromatic Channel

In order to investigate the mechanism of the chromatic channel, the spatial characteristics are measured by our recent study[23]. The experimental results suggest that the color adaptation has dependency on the wavelength of the adaptive light. It can not be explained by the Stiles's π mechanisms or a simple mutual interaction of the chromatic and the achromatic channels. Based on the measurement results, a parallel model has been proposed as shown in Fig. 5.

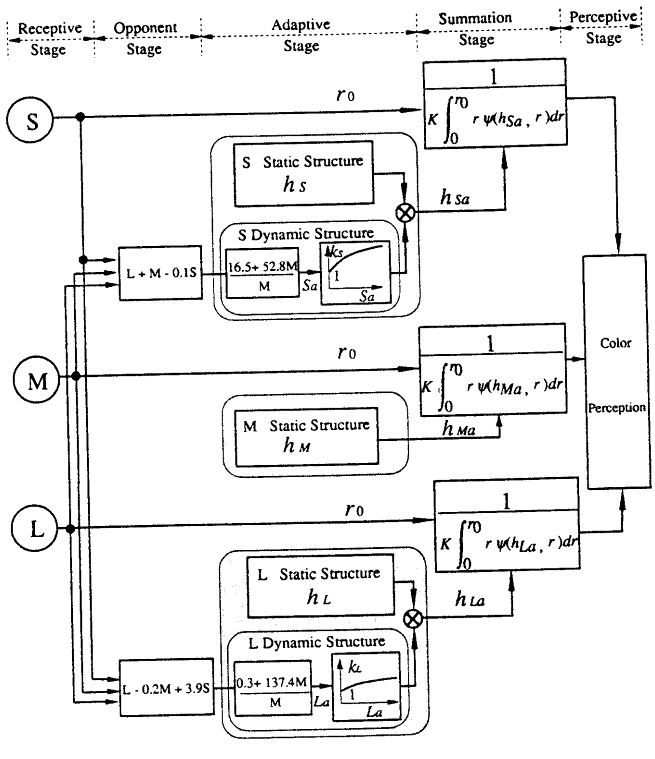

Fig. 5 A parallel model of the chromatic channel (Nishikawa, Wu & Kita 1994)

The parallel model is composed of the following five stages.

(1) *Receptive Stage*

This stage is same as to achromatic model. The input information is caught by the receptor *S*, *M* and *L* cones.

(2) *Opponent Stage*

The opponent stage is composed of two channels: the yellow-blue channel ($L+M-S$) and the red-green channel ($L-M+S$). Hering's opponent-color theory[24] is used here.

(3) *Adaptive Stage*

This stage is constituted by *S*, *M* and *L* three subsystems. Each system is composed of a static structure and a dynamic structure.

(4) *Summation Stage*

The calculation of this stage is based on the concept of the receptive field function [23].

(5) *Perceptive Stage*

In the final stage, the chromatic perception is calculated by three subsystems. They have different spatial and spectral characteristics.

5. A PARALLEL MODEL IN BINOCULAR VISION

Considering physiological structure as stated in Section 3, and the psychological experimental results of our previous studies in the monocular vision as stated above, the authors propose a parallel model of the binocular information processing as shown in Fig. 6. In this model, the authors make notice of spatial characteristic in the binocular information processing. In the monocular vision stage, the information is processed by several monocular units having different spatial characteristics, from low spatial frequency (lager circle symbols) to high spatial frequency (small circle symbols). In the binocular vision stage, the authors assume that the binocular information is processed by several binocular units having different spatial characteristics spreading their selectivity from low spatial frequency (larger ellipse symbol) to high spatial frequency (smaller ellipse symbol).

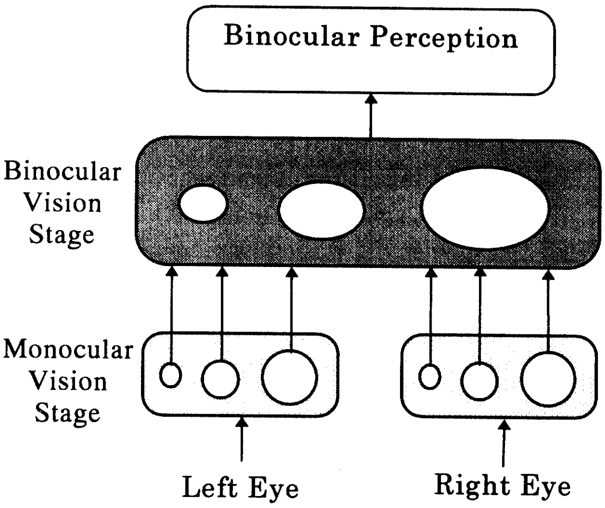

Fig. 6 A parallel model of the binocular vision

6. DISCUSSION

The proposed parallel model as stated above is based on the physiological structure and the results of our previous studies. Furthermore this model is supported by other recent studies. Wilson et al. [25] have measured the upper disparity limit for binocular single vision (the diplopia threshold) using stimuli containing information on two separate spatial scales. Specifically, these images were composed of spatially localized test patterns with a bandwidth of 1-octave spatial-frequency superimposed on a cosine grating having a different spatial frequency. Their experimental results are shown in Fig. 7. When the cosine frequency was 2.0 octaves below the peak of the test pattern, the range of fusion was greatly reduced to compare with the range in a experiment presenting the test pattern in isolation. However, when the cosine was 4.0 octaves below the test frequency, there was no reduction in the fusion range, and the test patterns were seen transparently in depth through the plane defined by the cosine grating. In addition, when the background cosine was 2.0 octaves above the test frequency of sixth difference-of-Gussian, no interaction was found. That is to say, Wilson's results suggest that the binocular information is processed by several subsystems and the interaction is existed among themselves.

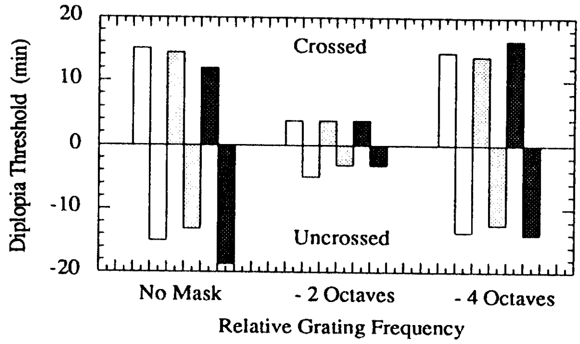

Fig. 7 Diplopia thresholds for three observers using high-spatial-frequency sixth Gaussian derivative test stimuli (Wilson et al. 1991)

As shown in Fig. 6, the proposed parallel model is a schematic diagram of the binocular information processing. In our future works, the details of the subsystems in the binocular vision are need to investigate by psychological experiments and quantitative analyses.

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人間両眼立体視におけるパラレルモデルの提案

呉　景龍　　　西川 禕 一

論文概要： 人間の両眼視システムは長期間を渡って進化され、非常に高性能な感覚系である。両眼視のメカニズムが解明されれば、視覚センサシステム、ロボットビージョンなどの技術にも、大きく貢献できるであろう。従来の生理学の研究により、網膜映像は低空間周波数から高空間周波数まで、異なる空間スケールで脳の視覚野に送られている。さらに、我々の最近の心理学実験の結果は単眼視覚系の明るさチャンネルと色チャンネルがパラレル構造を持っていることを示唆している。本論文では、生理学の知見および我々の従来研究の結果に基づいて両眼立体視におけるパラレルモデルを提案する。