Optica Applicata, Vol. XIX, No. 2, 1989

Optical model of human vision*

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An optical system simulating the visual tract in the brain has been tested experimentally. The consequences for optical data processing in the subsequent steps of the system are discussed and confronted with biological data.

1. Visual perception

Visual perception of animals as well as of human beings is the result of a long and complicated neural process which takes place in the brain [1]. The image introduced by the eye's lens is only a data base for the neural system. Some steps of the process are well known for the biologists, some remain unclear till now.

The system begins with gathering a discrete collection of neural impulses from the retina and ends with decisions important for survival of the animal (man). It is possible to construct an optical system which will secure the same object and will work in a similar way as the vision system does. This system, being a simple technical arrangement, can be helpful in discussing several problems of visual perception.

2. Optical model of vision

Optical correlator is a system which realizes the same aim as that of visual system. It consists of: i) an input plane where the optical signals (illuminated patterns) are introduced, ii) the memory where the signals are analysed, and iii) the output where the decisions are made about the introduced signals.

The decision concerning the survival are based on some peculiar features of the input image; for a frog, for instance, it is the velocity of a moving stimulus, while for man it is the shape of the object. Therefore, the input signal must be preprocessed at the very beginning of the system.

The extraction of shapes in an optical system is realized by spatial frequency pass-band filter. This filter must screen the zeroth and the highest spatial frequencies. In this way, the input image is transformed into a smeared contour pattern. The grey half-tones are lost and the sharpness of contours is equalized. The shapes of the object become distinctly exposed. In our experiments [2], the pass-band filter

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* This work has been presented at the VIII Polish-Czechoslovakian Optical Conference, Szklarska Poręba (Poland), September 13–16, 1988.

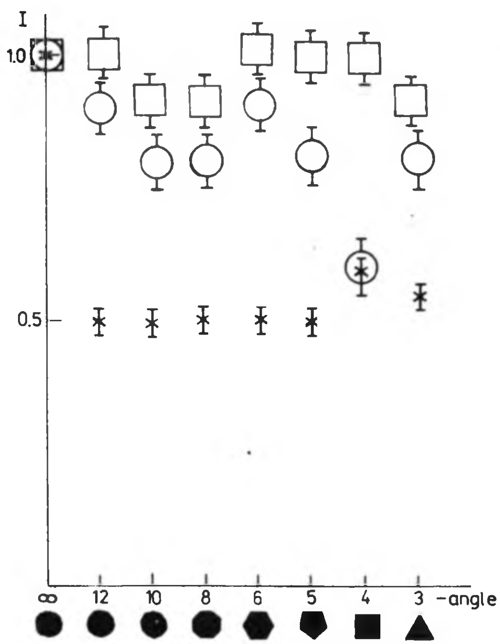
transmitted spatial frequencies from 2 l/mm to 100 l/mm. In work [3], the transforming filter has been constructed as a differentiating one. This filter corresponds to the initial transformation of eye stimuli in the vision. The high spatial frequencies of the object are there limited by the diameter of the pupil and the latter is well matched with the density of rods in the retina. The low spatial frequencies are lost in the visual neural tract at the very beginning, due to the side by side inhibition of neurons [4], [5].

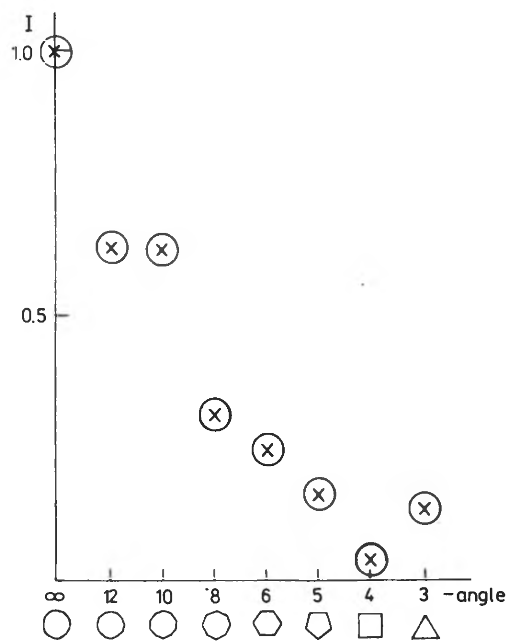
The initial preprocessing of the input signal is of a great importance for the decision making stage.

Let us discuss classification of the shapes in an optical correlator system. The classification is based on the value of intensity response in the correlation image. The intensity I measured in the center of correlation image can serve as the measure of similarity between the introduced and memorized signals [6], [7]

$$I = \left| \frac{\int S_0(x_0)\, S_M(x_0 - x)\, dx_0}{\int S_0(x_0) dx_0 \int S_M(x_0)\, dx_0} \right|^2_{x=0} = \left| \frac{\int S_0(x_0)\, S_M(x_0)\, dx_0}{\int S_0(x_0) dx_0 \int S_M(x_0)\, dx_0} \right|^2 .$$

In several correlator systems we have tested the dependence of intensity I on the shapes of introduced signals. A set of polygons is compared with the circle memorized in the matched filter. The obtained results [8] are completely different depending on whether the polygons are full figures or linear contours. The results are shown in Figs. 1 and 2. It is obvious that the discrimination of shapes increases





▲ Fig. 1. Plot of the similarity ratio I vs the number of vertices of tested patterns. The case of full figures

Fig. 2. Plot of the similarity ratio I vs the number of vertices of tested patterns. The case of contoures figures

distinctly for linear patterns. Moreover, the discrimination of shapes becomes only slightly dependent on the sharpness of contours [2]. The pass-band filter was used in confrontation of recognition of the same pattern but smeared to various degree. The results are given in the table.

Distande d in copying the pattern [mm]	Intensity I in the center of correlation	
	without filter	with filter
0	1	1
0.01	0.3	0.6
0.04	0.1	0.3

What are then the consequences of preprocessing the incoming signal? The discrimination of shapes increases, but the information about tiny details in the object is lost.

Perhaps the initial preprocessing of visual information in neural net has the same objective? Perhaps the mechanism of reminiscence is similar to that of the optical correlator, consisting in matching the introduced images with the templets beared in the brain? A question arises: what are the templates which form the memory?

Scene analysis is the next stage in the decisive visual system. Optical correlator is able to recognize a pattern as a whole or a part of a complex scene, if the part is essentially different from the background. In another case a coherent sum of equally weighting subcorrelations is formed at the output. Such a sum cannot be interpreted. The only way of scene analysis is to scan the input by a proper aperture. The complex scene can be then regarded as a spatially-temporal sum of elementary signals S_i

$$S = \sum_{x}\sum_{t} S_i(x_0 - \Delta x_i)T_0(t - \Delta t)$$

where T_0 is the transmittance of the used aperture, x_i is the distance at which the elementary signal S_i takes place inside the scene, and Δt is the duration of one step of the scanning. Images of correlations between elementary patterns and templet recorded in the matched filter occur sequentially one after another at different places of the output plane. Autocorrelation peak indicates the position of the elementary pattern identic with the templet. The example of decomposition of a complex scene into circles by means of the scanning technique is shown in Fig. 3 and 4 [9].

The experiments with scanning have demonstrated that only very simple patterns can be used as templets of elementary signals. The circles and cross-bars belong to well chosen patterns [10].

The mysterious eye movements may be analogous to the scanning procedure in optical correlator. The eye performs namely incessantly chaotic scanning movements over the input object [11]. The purpose of this effect is not fully clear. We know that the fixation points, where the eye stops at the moment, are grouped nearly peculiar

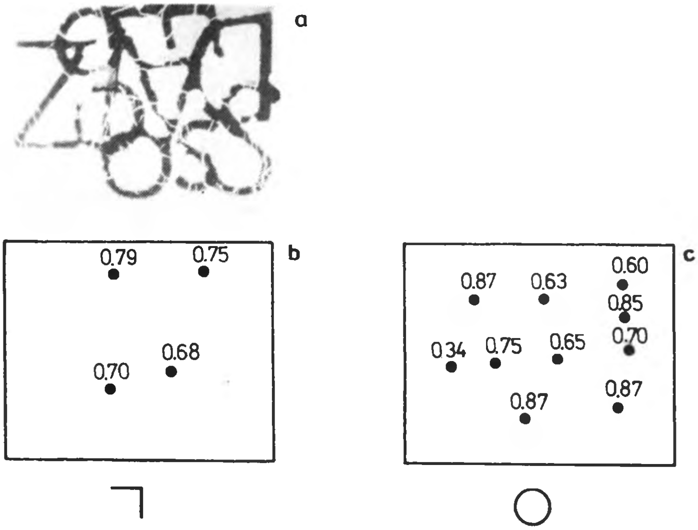


Fig. 3. Complex scene and spatial distribution of circles inside the scene found by examining the highest values of similarity ratio I in van der Lugt correlator system with scanning aperture: **a** — input scene, **b** — I_{max} distribution for a circle, **c** — for a cross-bar

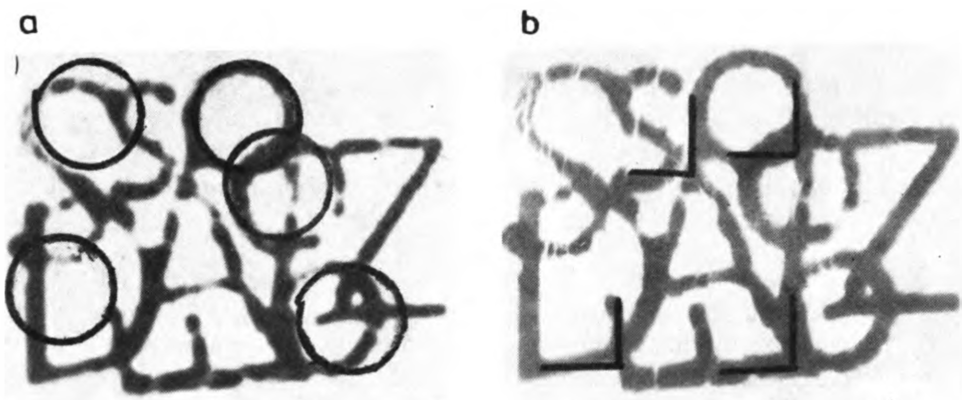


Fig. 4. Complex scene decomposed into (**a**) circles and (**b**) cross-bars

parts of the object inspected [12]. These parts are angles and circles. The eye movements are unavoided for visual perception, when the eye stays, the visual impression disappears.

Perhaps the scene analysis in the brain consists in matching some minute parts of the viewed object with a simple templet beared in the neural net (so-called image projection). The synthesis of a scene from the parts may not be unnecessary. Perhaps the memory exists in the form of sets of templets (or its impuls responses), and the decision taken are based on the founded elementary responses? The technical tool, such as optical correlator, operates in this manner.

How we can imagine the work of the human memory on the ground of the experiments with optical correlator? The data base consists of fixed neural impulses responding to several simple elementary patterns. These are spatially spread out in the neural net. When the preprocessed and decomposed input signal can excitate a proper combination of the impulses, it can be recognized and classified.

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Received September 13, 1988

Оптическая модель зрительного восприятия

В работе сопоставлен способ работы оптического коррелятора с действием зрительного восприятия. Значительное сходство между этими системами мы видим во вступительной обработке входного оптического сигнала, в анализе сложного сигнала и в использовании памяти. Составлены экспериментальные системы с биологическими данными из предметной литературы.