Improved Edge Detection by the Evaluation of Color Contrast Information

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Abstract

The IMA Research Group has developed an active vision system, called NAVIS, which is mainly based on neural models. It can roughly be separated into five functional components: camera control, form detection, attractivity calculation, attention selection, and object recognition. The form module initially consisted of a gray value channel for the computation of luminance contrast. In this paper we describe the extension of the gray value channel by two color opponent channels which contribute to the extraction of edges. With these new channels it is possible to detect isoluminant edges. Furthermore, our model achieves a new estimation of the edges caused by luminance and color contrast. The attention and recognition capabilities of NAVIS can be improved by this method as experimental results show.

1 The Neural-Active-Vision-System NAVIS

NAVIS is a biologically motivated active vision system designed to recognize complex objects within a non-uniform environment. Object recognition is done in a multistage fashion by first hypothesizing the presence and location of an object and afterwards identifying the object by its parts. A computer controlled camera mounted on a pan-tilt unit is used as the experimental platform for the evaluation of proposed concepts.

An overview of the NAVIS architecture is presented in fig. 1. It shows the five functional components for camera control, form detection, attractivity estimation, attention selection, and recognition which are executed counterclockwise. The recognition of an object takes several cycles (for details see [Götze 1996]).

2 Extension of the form module by color contrast detection

The form module (dark gray block in fig. 1) simulates parts of low-level human visual perception, especially the behavior of orientation specific cells in the striate cortex. It extracts oriented contour information by successive convolutions with specialized kernels [Drüe 1994]. Object parts, or forms, are represented by these contours. During recognition the system tries to match the stored forms with the presented image at the expected locations on the basis of a hypothesis generated by the recognition unit.

So far color information was only used in a region based feature extraction module to reduce illumination effects and evaluate attractivity regions for the gaze control unit [Bollmann 1996]. The edge detection of the form module operated on a gray value image. This approach has the disadvantage that isoluminant edges cannot be detected, i.e. edges with a color contrast but without a luminance contrast.

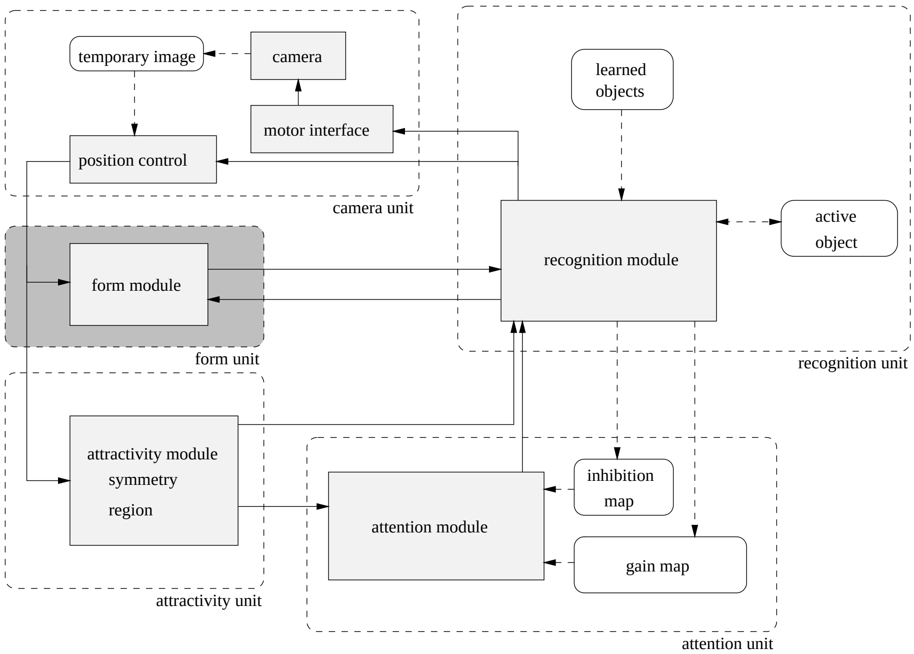


Fig. 1 System architecture

Though color contrast in the absence of luminance contrast rarely occurs in nature, psychophysical experiments under isoluminant conditions show minor impairments of the subjects' form detection capabilities [Javadnia 1988]. From these results De Valois [De Valois 1993] deduces the presence of color vision mechanisms under normal conditions and points out their benefits for object recognition. For example, a joint analysis of chromatic and achromatic variations allows to discriminate between luminance contrast produced by shadows and contrast produced by object borders. Furthermore it can be particularly useful to distinguish changes in the illuminant from changes in the object. Accordingly, the extension of the form module by color information can be considered not only as a necessity for the detection of isoluminant contours but also as a means for the interpretation of luminance edges.

Livingstone and Hubel [Livingstone 1988] tried to build a general view from the psychophysical and neurophysiological results. They relate the form recognition to the following processing stages:

1. parvocellular retinal ganglion cells (X-cells)
2. parvocellular layers in the lateral geniculate nucleus (LGN)
3. layer 4cβ of visual layer 1 in the primary visual cortex (V1)
4. interblobs in layers 2 and 3 of V1
5. pale stripes of V2
6. V3 and V4 [Davidoff 1991, p. 24]

It is important to note that stages 2 to 4 receive their major input from color-coded cells while the higher stages show no color specificity. This suggests that the information about the colors at the object borders is lost in the interblobs by the combination of color and luminance contrast channels.

Our approach is based on the work of Michael (e.g. [Michael 1978a-c]) who examined the color vision mechanisms in monkey striate cortex. His model is similar to the hierarchical model of Hubel and Wiesel [Hubel 1968] except for the fact that it deals with color contrast and not with luminance contrast information. Fig. 2.1 depicts the model according to Michael.

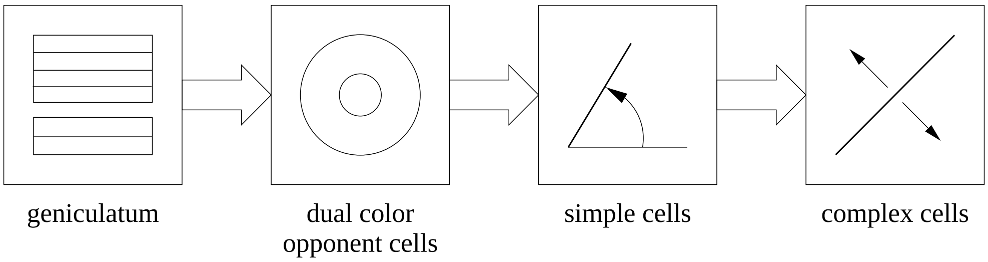


Fig. 2.1 Hierarchical model for the coding of color contrast information

Michael supposes the dual color opponent cells to be the first stage of cortical color contrast processing. Opponent color cells of the LGN whose behavior is similar to the type-II class described by Hubel and Wiesel converge on these cells. The receptive fields of type-II geniculate cells and dual color opponent cells are shown in fig. 2.2 for the red-green type. The blue-yellow type possesses similar receptive fields.

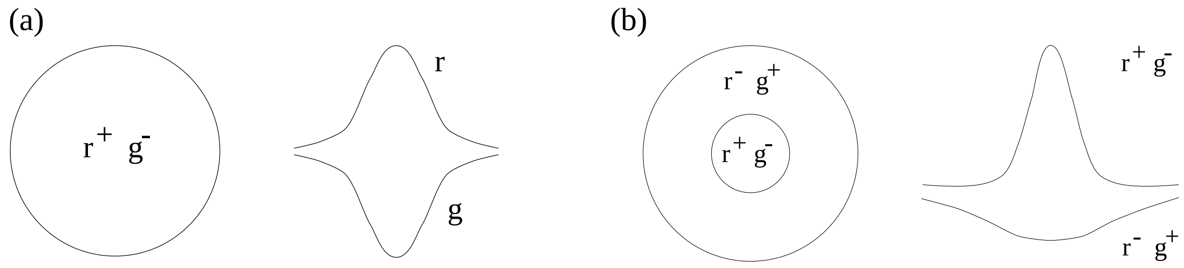


Fig. 2.2 Receptive fields of (a) type-II and (b) dual color opponent cells

Actually, the participation of type-II cells in the form recognition is controversial (for a discussion see [Billock 1991]). Ingling and Martinez ([Ingling 1983], [Martinez 1993]) and also Paulus et al. [Paulus 1986] suggest that dual color opponent cells are not directly built from any geniculate cell type, but from spatial filtering operations performed on type-I cells. Nevertheless, the exact wiring of the different neural layers is of secondary importance for our technical model. We are mainly interested in the reactions of the dual color opponent and simple cells. The complex cells which contribute to motion estimation are not implemented yet, but are expected to be embedded in the ongoing work on tracking.

The receptive fields of the different cell types are modelled as two-dimensional discrete convolution kernels. The convolution results (netto input of the cells) are weighted by tangenshyperbolicus mapping functions in imitation of the response of biological neurons. Fig. 2.3 illustrates the color processing steps for the red-green channel. The receptive fields of the first two layers (type-II and dual color opponent cells) are described by Difference-of-Gaussian functions. Similar operators have been used for other color spaces (e.g. [Carron 1994], [Cumani 1991]). In a third layer we have implemented simple cells with 24 different orientation preferences (resolution angle 15 degrees). Their receptive fields are described by a product of a sinus and a Gaussian function in one direction and a Difference-of-Gaussian function in the perpendicular direction.

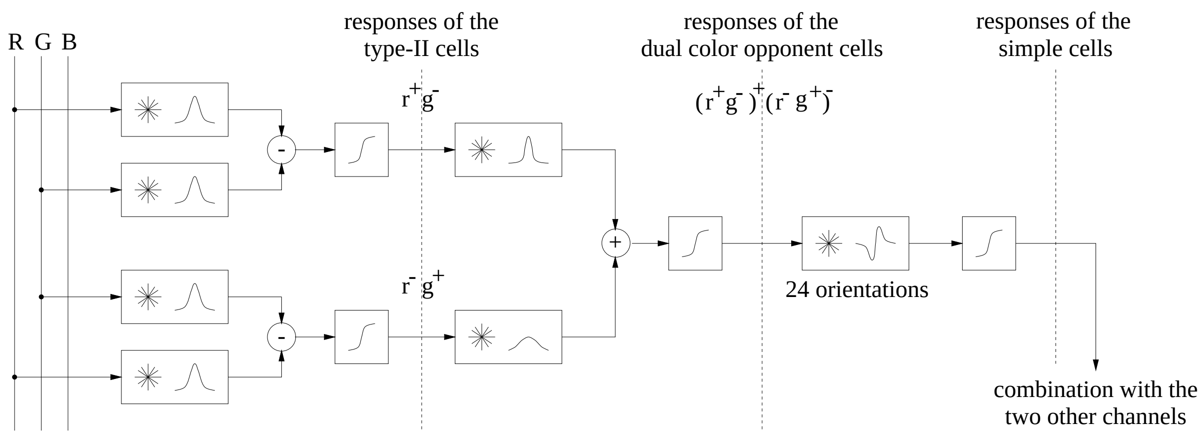


Fig. 2.3 Block diagram of the processing stages in the red-green channel

The activities of the color sensitive simple cells (red-green and blue-yellow channel) are combined with the activities of the luminance sensitive simple cells (gray value channel). This connection arises from the notion that the form recognition is color blind at higher stages in the visual cortex. In NAVIS a set of 10 operators is implemented to combine the three channels. The selectable operators are the maximum function, mean, fuzzy OR, algebraic sum, Hamacher sum, Einstein sum, and some more. In a sequencing stage a suppression of secondary maxima and orientations is performed to increase the resolution. The resulting contour images are presented to the attractivity and the recognition unit of NAVIS.

3 Experimental results

One of our experiments compares the results of the extended edge detection with those of the former exclusive luminance channel for equiluminant colored patches. Fig. 3.1 depicts the RGB values of the original image and the calculated luminance image. In NAVIS the luminance is computed by $L = 0.2125 \cdot R + 0.7154 \cdot G + 0.0721 \cdot B$ [ITU 1990]. It is not possible to detect any edges from the luminance image. The border detection results shown in fig. 3.2 result from a maximum operation on the three channels. Such an experiment shows obviously the benefits of the evaluation of color contrast information.

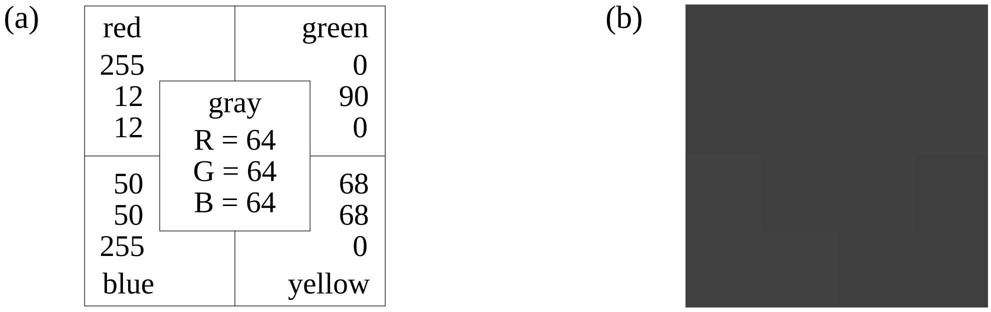


Fig. 3.1 (a) RGB values of the original image; (b) Equiluminant colored patches

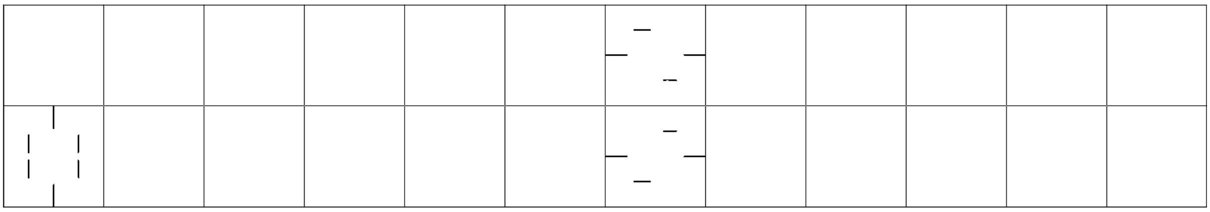
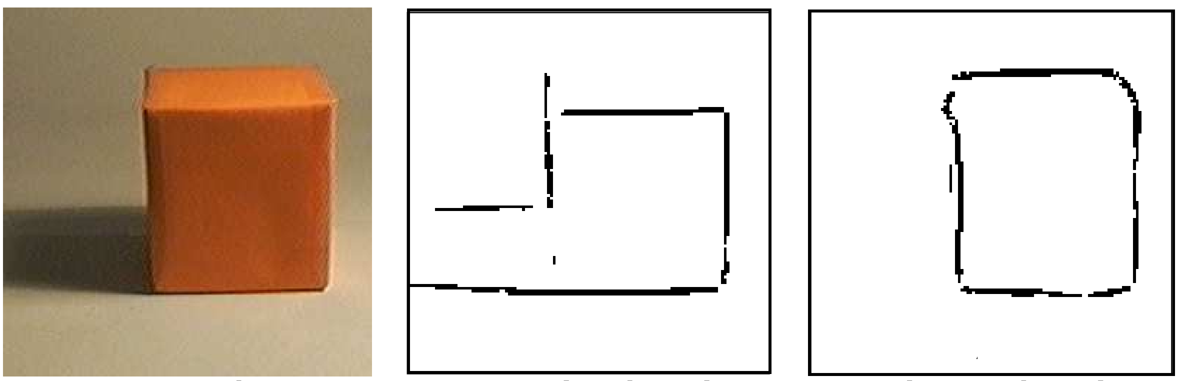


Fig. 3.2 Resulting edge images (24 orientations)

Another experiment shows how the introduced form detection can improve the attention selection of the active vision system NAVIS. An edge defined by both color and luminance contrast is likely to be associated with an object border, while an edge solely formed by a change of luminance is more likely to indicate a shadow border [De Valois 1993]. Such a discrimination is illustrated in fig. 3.3 (blue-yellow channel is omitted). The input image is an orange cube on a white table. In the gray value channel the borders of the shadow will cause an attention shift of NAVIS to the point of gravity of this pretended object. The edge detection results of the color opponent channels can prevent the system from this shift. This might avoid the rejection of a correct hypothesis regarding the presence of a certain object.



orange cube | gray value channel | red-green channel

Fig. 3.3 Edge detection results (summation of the 24 oriented bands for representation)

In this paper we could only present some examples of possible experiments. Nevertheless, these results demonstrate the benefits of the evaluation of color contrast information.

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