A promising approach to image processing based on neuromorphic decoding in the Marr's paradigm

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***Abstract*— In computer vision tasks, detecting object boundaries, as well as their textures, is one of the key ones. Despite the fact that significant progress has already been made in object recognition tasks, existing processing models and algorithms are significantly inferior to the capabilities of the visual system. In previous works, several methods have been proposed to determine the contours of objects, allowing not only to highlight the boundaries of each object in the image, but also to significantly eliminate distortions associated with the blurring of fuzzy images, reduce the noise component of the image, and restore the indistinctly defined border. This article discusses current issues in computer vision using the example of a previously developed bioinspired image processing algorithm.**

Keywords*— *neuromorphic methods, sample representation, receptive fields, image contrast enhancement by underlining borders

I. INTRODUCTION

Modern algorithms and methods of computer vision make it possible to obtain results comparable and sometimes even superior to human capabilities. However, the implementation of these methods requires significant expenditures in memory resources and energy for data transmission and processing. To minimize the resources consumed, modern methods make them similar to biological analogues, in particular, well-known neuromechanisms of the human visual system are used for processing visual data, which are represented by a number of bioinspersed image processing algorithms. Based on the functional features of the visual system, David Marr formulated the computational theory of vision, also known as the Marr paradigm [1]. His theory is actively used in machine learning tasks to detect the boundaries of objects.

In our previous work, we have obtained a number of successful results related to data encoding and subsequent recovery using neurophysiological data, in particular, the receptive field model and such features of bipolar cells of the retina of the eye as lateral inhibition and the presence of division into ON-cells and OFF-cells [2, 3]. We have developed a statistical model of image formation in the form of a stream of homogeneous events (the Poisson process), which is an analog of the external radiation recorded by the retina [4]. The next step was to develop a data encoding algorithm that formally corresponds to the mechanism of lateral inhibition of neurons. Finally, a data decoding model was presented, which made it possible to restore the image qualitatively from the point of view of perceptual perception.

In this paper, the results obtained are discussed and algorithms and methods for identifying boundaries for implementing computer vision tasks are considered.

II. THE MARR'S OPERATOR FOR BOUNDARY RECONSTRUCTION

Previously, we proposed a procedure for encoding a sample representation in the following form:

$$\delta\bar{I} = \frac{k^3-1}{4k^3} Z\Delta I(\vec{0}), \tag{1}$$

where k is a coefficient greater than zero, Z is the magnitude of the moment of inertia, and Δ is the Laplace operator, $\delta\bar{I} = \bar{I} - \bar{I}_c$ is the intensity difference for the entire receptive field and its center:

$$\delta\bar{I} = \bar{I} - \bar{I}_c = \frac{n}{\sigma} - \frac{n_c}{\sigma_c} = -\frac{1}{\sigma_c}\delta,\ \delta > 0. \tag{2}$$

It is an analogy between the function of receptive fields, where $\delta = n_c - (\sigma_c/\sigma)\,n$, the total number n of counts belonging to this receptive field, n_c is the number of counts in its center, $\sigma = |\Delta|$ and $\sigma_c = |\Delta_c|$ are areas of typical field Δ and its center Δ_c.

The equation (2) calculates the intensity defect, with the Marr operator [5], which serves to detect the edges of objects. Lines of sharp change in intensity (zero lines) Marr characterized by the condition $\Delta I(\vec{x}) = 0$. It turned out to be quite convenient for defining the contours of objects. For this, well-known low-resolution image interpolation methods were used with the addition of previously recorded discrepancy coefficients. Considering that the number of counts $\{n\}$ of the code is essentially the output of a smoothing filter with a sliding window of the area of the receptive field σ, we can immediately say that the distortions associated with this part of the code have the form of blurring the original image, as a result of which there is a significant smoothing of the edges of objects. If we add to the count numbers a part of the code $\{\delta\}$ containing the coefficients of discrepancy for the entire set of receptive field, we come to the realization of a step filter, constant and positive in the area of the center of receptive field, and constant but negative on its periphery.

This procedure made it possible to minimize the distortions resulting from the use of a smoothing filter, replacing it with a filter similar to a step filter. Such filters are known in the field of digital image processing, in particular, our proposed filter exactly corresponds to the COSO filter proposed for the LoG filter response model used in the works of Marr and Hildert in the theory of boundary detection [6].

Since the discrepancy coefficients $\{\delta\}$ used turned out to be related to the Laplace operator, the zeros of linear interpolation along the lattice represent areas of sharp intensity differences, which is described by Marr's thesis. Further restoration of boundaries can be reduced to the use of numerous edge interpolation methods that represent the best perceptual quality of perception, and can be used in computer vision algorithms.

III. Algorithm implementation

The 481×321 pixel color image "29030" was taken from the BSDS500 image database [7] to demonstrate the edges highlighting (Fig. 1).

Fig. 1. An original image “29030” from database BSDS500 [7].

The image was reduced to grayscale, then a standard image encoding procedure was performed. At this step a sample representation of original image was formed. The number of counts in this representation is n = 10.000.000. The data obtained was then processed using the bioinspired algorithm based on the receptive field model. (Fig. 2)

Fig. 2. Decoding of the sample representation of original image, containing 10.000.000 counts

To eliminate the blurriness of the image and emphasize the edges of objects, an algorithm was applied to highlight features inspired by the mechanism of lateral inhibition of retinal cells. The areas of strong radiation intensity difference were appropriately marked, the corresponding representation is shown in Figure 3.

Fig.3. Highlighting the features associated with the change in radiation intensity in the image

The next step is to restore the boundary of the object for further processing and analysis. For this, the areas of intensity difference were sequentially combined into lines to form the edge of the object. Since the sizes of such lines depend on the size of the receptive fields, the algorithm becomes quite selective, allowing both to whiten the border of the object in the image and its textured features. To qualitatively highlight the boundary, a set obtained from the original image was processed by varying the size of the receptive fields, which was further summed and filtered from noise signal (Fig. 4).

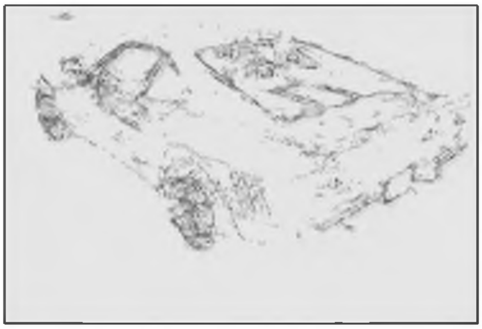

Fig. 4. Extraction of edges by using an algorithm based on Marr's thesis

IV. Conclusion

The work analyzed the development of bioinspired methods for determining the edges of objects, revealed the neuromechanisms of the visual system aimed at image registration and detection of object edges, which are actively used in modern machine learning models in image processing. The edge detection model based on the Marr operator has been formalized. The resulting algorithm made it possible to highlight not only the border area in the image taken from BSDS500, but also the textures of object. Based on the results obtained, the authors hope for further development of neurobiological methods in the field of image processing.

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