Available online at www.sciencedirect.com
ScienceDirect
Image and Vision Computing 25 (2007) 1282–1290
www.elsevier.com/locate/imavis

Contour detection based on contextual influences

Qiling Tang [a], Nong Sang [a,*], Tianxu Zhang [b]

[a] *Institute for Pattern Recognition and Artificial Intelligence, Huazhong University of Science and Technology, Wuhan 430074, PR China*
[b] *Key Laboratory of Ministry of Education for Image Processing and Intelligent Control, Wuhan 430074, PR China*

Received 28 March 2005; received in revised form 20 April 2006; accepted 9 August 2006

Abstract

A contour detection model, inspired by the behavior of the primary visual cortex, is presented. The response of a central stimulus in the receptive field is affected by the presence of surrounding stimuli – for some stimulus conditions, the response is suppressed and for other conditions the response is enhanced. The visual mechanisms of contextual influences are utilized to extract "coherent" configurations. This is mainly due to the following two reasons: (1) on the one hand, a smooth contour can yield collinear excitation, which highlights smooth contours from irregularly textured surround; (2) on the other hand, similar orientation textures receive iso-orientation surround suppression and region boundary is subjected to the less inhibition, which makes boundary more salient for perceptual pop-out. Accordingly, smooth contours progressively stand out from their surround and at the same time textures are gradually suppressed by their surround through dynamic fine-tuning of contextual information. The proposed method which distinguishes between contours and texture edges is more effective for contour-based object recognition tasks. Initial experiments show that the model can be successfully applied to contour detection. Especially, when object contours are lumped together with unwantedly cluttered surround, the advantage of our approach is more prominent. This study provides a biological scheme for contour detection in computer vision.

Keywords: Contour detection; Contextual influences; Visual mechanisms; Suppression; Enhancement

1. Introduction

Edge detection is a foundation of image segmentation and feature extraction and plays an important role in image analysis and understanding. Consequently, it is one of the most intensively studied subproblems in computer vision. Many edge detection algorithms have been reported, whereas most of the edge detectors do not distinguish between object contours and edges originating from textured regions [1–5], so that their results contain lots of unwanted edges which make part of texture. However, so far as human visual perception is concerned, smooth contours with coherent spatial configurations and texture boundaries where there is a change in orientation have the higher saliencies and can be more easily detected. The visual mechanisms provide a biological strategy for contour detection.

Grigorescu et al. [6] used the method of non-classical receptive field (non-CRF) inhibition to effectively suppress surrounding textures and admirably preserve isolated contours. They regarded isolated lines and edges as non-texture features, which are not affected by the inhibition, while groups of lines and edges viewed as texture features are suppressed. But there exist two major defects in their work: (1) owing to taking only surround inhibition effect into account, contours will also be inhibited as textures when contours are embedded in textured surround; and (2) their model lacks of a dynamic feedback mechanism, thus the ability to utilize contextual interactions is limited. For smooth contours, in addition to the surround inhibition, what is more, "coherent" configurations produce collinear excitation by contextual interactions, which makes contours relatively more salient and pop out from the background.

* Corresponding author. Tel.: +86 27 87541761; Fax: +86 27 87543594.
E-mail addresses: tqlinn@sohu.com (Q. Tang), nsang@hust.edu.cn (N. Sang).

0262-8856/$ - see front matter
doi:10.1016/j.imavis.2006.08.007

Stimuli outside classical receptive fields exert a significant influence over the activities of neurons in the primary visual cortex. Parallel physiological and anatomical studies of striate cortex in cat and monkey revealed similar lateral interactions mediated by short- and long-range horizontal connections showing collinear excitation and iso-orientation surround inhibition [7–12]. Levitt and Lund [13] demonstrated that the responses to a stimulus placed within a V1 neuron's receptive field can be either increased or decreased by adding a stimulus in the region surrounding the receptive field. Knierim and van Essen [14] observed experimentally that the response to stimulus in the CRF is suppressed significantly by similarly oriented stimuli in the surround – iso-orientation suppression. The suppression is reduced when the orientations of the surround stimuli are random or different from the stimulus in the RF. However, if the surround stimuli are aligned with the optimal stimulus inside the RF to form a smooth contour, then suppression becomes facilitation [15,16]. Whether the response to stimuli presented within the receptive field can be enhanced or suppressed by other stimuli falling outside the receptive field depends on the relative orientation of pattern elements inside and outside the receptive field [17]. Bonneh and Sagi [8] found that detectability depends on stimulus geometry and is constrained by collinearity and proximity spatial relationships, and therefore a 'coherent' configuration (e.g. smooth contour) is more easily detected than a 'non-coherent' one (e.g. jagged contour).

Li's research [16,18] manifested further that the contextual influence can indeed selectively enhance neural responses to segments of smooth contours against a noisy background. They considered that pre-attentive visual mechanisms in V1 locate the region boundaries by locating where homogeneities or translation invariance in inputs break down, and highlight such locations by higher neural responses. Strengthening neural responses to these important image locations make the neural activities near boundaries higher than elsewhere. [19] supposed that the neurons in the prime visual cortex perform contour detection in a functional network fashion.

The mechanisms of visual perception provide a biological method for salient contour detection. According to the characteristics that local elements on the smooth contour have coherent spatial configurations, we detect contours through the interactions of the contextual information, strengthening coherent configurations while weakening surrounding textures.

The paper is organized as follows. In Section 2 we use Gabor energy filters to model the function of complex cells and introduce the mechanisms of inhibition and enhancement. In Section 3, some practical aspects in the application of the method are discussed, and then we test the performance of this algorithm through various synthetic and natural images, and compare with Gabor energy edge detector and the contour detection operators proposed by Grigorescu et al. Finally, we draw conclusions and present future work in Section 4.

2. Algorithm implementation

2.1. Spatial filters

Most simple cells in the primary visual cortex are selective for orientation of patterns falling within a restricted region of visual space [20–22]. These cells have their own preferred orientations within the range of 0 to $\pi/2$. These simple cells behave in approximately linear fashion, and thus they can be regarded as linear spatial filters [23]. Psychophysical and physiological evidences suggest that the visual input is first decomposed by local analyzers or channels tuned to specific properties such as orientation, spatial frequency and direction of motion [8]. As linear filters, 2D Gabor functions with selected frequency and orientation can effectively model the receptive field profiles of simple cells in mammalian visual cortex [24–26], which realizes mathematical formulation of the receptive field.

A Gabor function is a Gaussian modulated by a complex sinusoid, as the following equation illustrates:

$$h(x,y) = g(x',y')\exp(j2\pi Fx') \quad (1)$$

where $(x',y') = (x\cos\theta + y\sin\theta, -x\sin\theta + y\cos\theta)$, θ denotes the orientation of the filter. Any desired orientation can be achieved via a rigid rotation in the x–y plane. F denotes the spatial center frequency, which determines the position of center of a bandpass filter in the frequency domain. $g(x,y)$ is the following 2-D Gaussian:

$$g(x,y) = \frac{1}{2\pi\sigma_x\sigma_y}\exp\left\{-\frac{1}{2}\left[\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2\right]\right\} \quad (2)$$

where σ_x and σ_y denote the horizontal and vertical spatial extent of the filter, and they are utilized to determine the size of the RF. The values of σ_x and σ_y are related to the half-peak magnitude frequency bandwidth and orientation bandwidth of the filter, and are given by [27]

$$\sigma_x = \sqrt{\frac{\ln 2}{2}}\frac{1}{\pi F}\frac{2^{B_F}+1}{2^{B_F}-1} \quad (3)$$

$$\sigma_y = \sqrt{\frac{\ln 2}{2}}\frac{1}{\pi F}\frac{1}{\tan(B_\theta/2)} \quad (4)$$

where the frequency bandwidth in octaves, B_F, reflects the localization capability of the filter in the spatial and frequency domains, and the orientation bandwidth in radians, B_θ, reflects the localization capability of the filter for orientations.

Morrone and Burr [28] showed that the maxima of local energy occur at points where the phases of the Fourier components are maximally similar. They suggested that feature detection in human visual system proceeds by first computing the local energy at every point in the retinal image and then searching for the local maxima. In the local energy model, a given image is filtered with a set of filters that have identical amplitude spectra but orthogonal phase spectra [29]. The Gabor function is chosen to implement the local energy model because it is highly directional