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Salient contour extraction from complex natural scene in night vision image

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HIGHLIGHTS

- We analyze LLL and infrared images with natural scene base on nCRF mechanisms.
- An optimized compound modulation method extracts contour from night vision image.
- MFC weighting inhibition model improves surrounding inhibition.
- FC facilitation model achieves the connection of discontinuous contours.
- A multi-scale iterative attention method accomplishes dynamic modulation process.

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ABSTRACT

The theory of center-surround interaction in non-classical receptive field can be applied in night vision information processing. In this work, an optimized compound receptive field modulation method is proposed to extract salient contour from complex natural scene in low-light-level (LLL) and infrared images. The kernel idea is that multi-feature analysis can recognize the inhomogeneity in modulatory coverage more accurately and that center and surround with the grouping structure satisfying Gestalt rule deserves high connection-probability. Computationally, a multi-feature contrast weighted inhibition model is presented to suppress background and lower mutual inhibition among contour elements; a fuzzy connection facilitation model is proposed to achieve the enhancement of contour response, the connection of discontinuous contour and the further elimination of randomly distributed noise and texture; a multi-scale iterative attention method is designed to accomplish dynamic modulation process and extract contours of targets in multi-size. This work provides a series of biologically motivated computational visual models with high-performance for contour detection from cluttered scene in night vision images.

1. Introduction

Contour extraction plays an important role in night vision images (low-light-level (LLL) and infrared images) understanding. Most applications of night vision target detection and recognition are in outdoor scene, which contains a great deal of natural texture like grass or foliage. The traditional edge detection operators, such as Canny, retain many non-contour boundaries. So how to eliminate uninteresting local boundaries engendered from textures and maintain the integrated contour are the major problems in night vision contour extraction.

Many solutions to extract contour from complex scene are proposed. In those methods, contour extraction through non-classical receptive field model based on the mechanism of biological vision [1] is distinguished by remarkable performance in the high-quality visible images. The area beyond classical receptive field (CRF) of neurons in primary visual cortex (V1), namely non-classical receptive field (nCRF), can modulate the stimuli response in CRF [2–10]. It has been found that the majority of the surround modulation is suppressive, which makes the isolated contour more significant than homogeneous background. Grigorescu et al. [2,3] proposed a series of related nCRF inhibition models to extract contour, including isotropic and anisotropic inhibition models [4], which utilize surround suppression in center direction to weaken natural texture. Giuseppe et al. [5] developed a multi-resolution contour detection method based on Bayesian denoising and a surround inhibition technique. The model built by Sang et al. [6] with butterfly-shaped subregion, weighting inhibition by the difference of stimulus-direction between CRF and nCRF, can decrease the impact of collinear suppression. Ursino et al. [7,8] introduced level attention mechanism to gain contour in different scales. Zeng et al. [9,10] improved the butterfly-shaped inhibition to present a two-scale based contour extraction model and an orientation-selective inhibition model.

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These approaches work well on suppressing background in visible images with high resolution, as is shown in Fig. 1, but they do not always perform well in LLL and infrared images. Compared with high-quality visible image, heavier noise and lower contrast in night vision images lead to inaccurate and cracked contour, and it is difficult to suppress natural texture. So in this paper, we design a reasonable inhibition model for contour extraction in night vision image, namely multi-feature contrast (MFC) weighted inhibition model.

On the other hand, inhibition weakens the strength of contour response. Contours in night vision image are prone to disconnect due to imaging characteristics, surround inhibition and noise interference, which will affect the subsequent target recognition.

Some physiological findings [11] have shown that modulations from nCRF are both inhibition and facilitation. Tang et al. [12,13] added collinear excitation in nCRF inhibition model, which calculates facilitation based on curvature in grouping properties to enhance the response of contour points. In the aspect of contour grouping, Sha et al. [14] proposed a significance calculation method based on curvature change and developed a grouping algorithm to extract remarkable curve. Geisler et al. [15] testified that contour grouping in natural scene corresponds with the co-circularity rule by studying the statistical properties of contours in natural image, and carried out a maximum likelihood local grouping function for contour. Elder et al. [16] studied the statistical properties of contour perceptual organization in Gestalt rules, including proximity, continuity and similarity, and suggested a Bayesian ratio model to detect contour. Wang et al. [17,18] provided a ratio-contour method to extract significant closed contour based on graph model. Guy et al. [19–21] developed a global cognitive model, namely tensor voting, to infer significant structures in image by tensor analysis and neighbor voting on each point. These contour grouping models devote to organize local segments to global contour information.

However, it is difficult to realize accurate contour connection through single grouping rule. In this paper, more contour grouping constraints are introduced to consider facilitation mechanism. We propose a fuzzy connection (FC) facilitation model to enhance weak contours and connect discontinuous contours to keep the integrated salient contours.

A multi-scale iterative attention method proposed in this paper, combining the MFC weighted inhibition model and FC facilitation model, realizes the optimized compound modulation. It primarily solves the problems of surrounding suppression and contour connection in LLL and infrared images.

The rest of this paper is organized as follows. Section 2 details our method of salient contour extraction in night vision images. Section 3 discusses the analysis of presented models. Section 4 gives the practical application and performance of our method in LLL and infrared images in nature scenes. Finally, Section 5 summarizes the main conclusions of this paper and the future works.

2. Visual model of salient contour extraction in night vision

2.1. nCRF model

Two-dimensional Gabor function is used to describe the receptive field profile of simple cells in visual cortex. The response modulus of odd–even pair of Gabor filters, called Gabor energy, can effectively models fundamental characteristics of typical complex cells, which can be seen as local orientation energy operators [22]. The maximum response of complex cell is used to accurate positioning edge and line in graphics. So Gabor energy is chosen to simulate the activities of complex cell. Two-dimensional Gabor filter can be expressed as follow.

$$g_{\lambda\sigma\varphi}(x,y;\theta) = \exp\left(-\frac{\tilde{x}^2+\gamma^2\tilde{y}^2}{2\sigma^2}\right)\cdot\cos\left(2\pi\frac{\tilde{x}}{\lambda}+\varphi\right) \quad (1)$$

where $\tilde{x} = x\cos\theta + y\sin\theta$, $\tilde{y} = -x\sin\theta + y\cos\theta$, in which θ is the preferred orientation of CRF; φ is phase offset; $g_{\lambda\sigma\varphi}(x,y;\theta)$ with $\varphi = 0$ and $\varphi = \pi/2$ represent the even and odd Gabor filter respectively; γ is the spatial aspect ratio, which determines the eccentricity of the Gaussian envelope; λ is wavelength; σ is the standard deviation of Gaussian factor, which decides the area of the Gabor simulated CRF; σ/λ represents the spatial frequency bandwidth.

Response of simple cells $r_{\lambda\sigma\theta\varphi}$ is given as the convolution of Gabor function and image I. Neuronal response to stimulus in CRF $E_\sigma(x, y; \theta_i)$ is defined as the combination of orthogonal pair of simple cells' responses.

$$r_{\lambda\sigma\varphi}(x,y;\theta) = I(x,y) * g_{\lambda\sigma\varphi}(x,y;\theta) \quad (2)$$

$$E_\sigma^2(x,y;\theta_i) = r_{\lambda\sigma 0}^2(x,y;\theta_i) + r_{\lambda\sigma\pi/2}^2(x,y;\theta_i) \quad (3)$$

where Gabor energy of CRF is divided into N_θ directions: $\theta_i = i\pi/N_\theta$, $i = 0,1,\ldots,N_\theta - 1$. According to [9] we set $N_\theta = 12$, $\gamma = 0.5$, $\sigma/\lambda = 0.56$. σ is a variable in our experiments. Output response of CRF is the maximum of $E_\sigma(x, y; \theta_i)$ over all orientations.

Fig. 1. Results of contour extraction in natural images. The columns from lift to right represent the original images, outputs of canny, butterfly-shaped inhibition [6], orientation-selective inhibition [10] and two-scale inhibition [9] models, respectively.