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An improved pulse coupled neural network with spectral residual for infrared pedestrian segmentation ☆

Fuliang He [a,b,*], Yongcai Guo [a,*], Chao Gao [a]

[a] Key Laboratory of Optoelectronic Technology and Systems of the Ministry of Education, Chongqing University, Chongqing 40044, China
[b] College of Electronic and Information Engineering, Southwest University, Chongqing 400715, China

HIGHLIGHTS

- This model is appropriate for the pedestrian segmentation of the infrared image.
- The infrared noise suppression structure is designed based on anisotropic Gaussian kernels.
- The spectral residual salient information is introduced to enhance the details of the result.
- The PCNN model is simplified to apply to infrared image segmentation easily and efficiently.

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ABSTRACT

Pulse coupled neural network (PCNN) has become a significant tool for the infrared pedestrian segmentation, and a variety of relevant methods have been developed at present. However, these existing models commonly have several problems of the poor adaptability of infrared noise, the inaccuracy of segmentation results, and the fairly complex determination of parameters in current methods. This paper presents an improved PCNN model that integrates the simplified framework and spectral residual to alleviate the above problem. In this model, firstly, the weight matrix of the feeding input field is designed by the anisotropic Gaussian kernels (ANGKs), in order to suppress the infrared noise effectively. Secondly, the normalized spectral residual saliency is introduced as linking coefficient to enhance the edges and structural characteristics of segmented pedestrians remarkably. Finally, the improved dynamic threshold based on the average gray values of the iterative segmentation is employed to simplify the original PCNN model. Experiments on the IEEE OTCBVS benchmark and the infrared pedestrian image database built by our laboratory, demonstrate that the superiority of both subjective visual effects and objective quantitative evaluations in information differences and segmentation errors in our model, compared with other classic segmentation methods.

1. Introduction

In the recent era, owing to the great development of uncooled infrared detector and processor, the relevant applications and techniques of infrared image play an increasingly significant role in civilian and military application, such as vehicle driving [1,2], medical imaging [3], safety guard monitoring [4,5] and soldierly scouting [6,7]. In these techniques, infrared image segmentation is actively investigated by the computer vision community, as the basis of feature extraction, state analysis and pattern recognition in the field of infrared image processing. There are numerous algorithms proposed in the literature, which include threshold detection algorithms, region-based segmentation algorithms, feature-driven approaches and model-driven methods.

The pulse coupled neural network (PCNN), which is a kind of model-driven method, has been widely employed in image segmentation, due to its unique characteristics of self-organizing networks, a single layer organized in the two-dimensional array of linked pulse coupled neurons, and pulse synchronization.

Whereas some obvious defects of model constrain the further application of PCNN in infrared image segmentation. Firstly, the complex framework and the weak self-adaptability of parameter

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* Corresponding authors at: Key Laboratory of Optoelectronic Technology and Systems of the Ministry of Education, Chongqing University, Chongqing 40044, China.

E-mail addresses: lighter@swu.edu.cn (F. He), ycguo@cqu.edu.cn (Y. Guo), gaoc@cqu.edu.cn (C. Gao).

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adjustment exist widely in the current PCNN segmentation models. So far, many researchers have been attempting to propose modified or simplified model. Kuntimad et al. [8] introduced connected PCNN to perfectly segment digital images even when there was a considerable overlap in the intensity ranges of adjacent regions as early as in 1999. In recent years, lots of studies in this area have been published. Wei et al. [9] built adaptive threshold time constant of PCNN model for automatic image segmentation, and the parameter settings could be studied to ensure that the threshold decay of PCNN would be adaptively adjusted according to the overall characteristics of the image. Gao, Zhou et al. [10–12] explored an iterative threshold segmentation model of modified PCNN, in order to extract the target completely. Chen et al. [13] applied the static spatial properties of the original image to express the relationship between these parameters, and the parameter setting methods of PCNN have been presented consequently. Chen et al. [14] also brought forward the region-based object recognition (RBOR) method to identify objects of interest from complex real-world scenes based on simplified PCNN. However, only the values of partial parameters have been automatically set in above approaches, and the appropriate values of other parameters are set only by manual or estimation, such as the linking strength β of input field particularly.

Additionally, motivated by the problem of the all parameters self-adaptive adjusting in PCNN, many researchers have attempted to use optimization theory to overcome it. Tan and Isa [15] utilized a particle swarm optimization (PSO) method with mutual information to optimize modified PCNN for segmentation and detection of human. Man et al. [16] presented a novel method of PCNN with a spiral optimization for image segmentation. Gómez et al. [17] extended evolutionary PCNN to segment breast lesions on ultrasonography, which combined the PCNN model and an adaptive differential evolution (JADE) algorithm. Xu et al. [18] devised a novel algorithm of the medical image segmentation, which combines the self-adaptive PCNN with the ant colony optimization (ACO) algorithm. However, these algorithms have to endure a heavy training, which cost a lot of time consuming and may not be available in practice, in spite of the simultaneous adjusting of multiple parameters in PCNN model.

Lastly, most critically, these current PCNN methods could not effectively suppress infrared noise which usually led to the blurred edges of the targets, when they are directly applied to infrared pedestrian segmentation. This is mainly due to mostly parameters of these PCNN models are only determined by the spatial distribution information of pixels.

Therefore, We specifically proposed a new model to merge the improved pulse coupled neural network and the spectral residual in an appropriate way, which could not only simplify the structure of the PCNN, but also enhance the details of the segmentation results by the frequency information of the infrared image. The performance of the proposed method is experimentally verified by comparing the results with some other segmentation methods qualitatively and quantitatively.

The remainder of the paper is organized as follows. Section 2 introduces the improved PCNN model, and presents parameters setting criteria to advance the final results. Experimental results and algorithm evaluations compared with current segmentation methods are shown in Section 3. And, the conclusions of our research are drawn in Section 4.

2. Improved PCNN model

Based on a principle of the mammal's visual cortex neurons, the original PCNN model was designed by Eckhorn et al. [19]. Considering that this model has the excellent property of effective simulation of the synchronous firing phenomenon, it is appropriate for pedestrian segmentation of the visible light image, and can be excellent to group the pixels with similar gray levels together and reduce discontinuousness on the edge of targets. However, the performance of available segmenting in the infrared image using the original PCNN is limited, due to its complicated framework and the influence of the infrared noise. Therefore, we have improved the original PCNN model based on the characteristics of infrared image, so as to segment pedestrians with more details effectively and efficiently.

The structure of a single pulse coupled neuron in the improved PCNN model is shown in Fig. 1. And its mathematical descriptions are defined as follows:

$$F_{ij}[n] = \sum_{k,l} M_{ij,kl} I_{kl}, \tag{1}$$

$$L_{ij}[n] = \sum_{k,l} W_{ij,kl} Y_{kl}[n-1], \tag{2}$$

$$U_{ij}[n] = F_{ij}[n]\left(1 + \beta_{ij}^{SR} L_{ij}[n]\right), \tag{3}$$

$$Y_{ij}[n] = \begin{cases} 1, & U_{ij}[n] > \delta E_{ij}[n-1] \\ 0, & otherwise \end{cases}, \tag{4}$$

$$E_{ij}[n] = \overline{m}(n), \tag{5}$$

where I_{kl} is defined the external input stimulus as gray-level matrix in the 8-point neighborhood of the center pixel (i,j); the weight matrix $M_{ij,kl}$ is designed to remove the infrared noise as the filter based on anisotropic Gaussian kernels; β_{ij}^{SR} denotes the normalized spectral residual to describe the salient regions of the pedestrian by frequency information; δ represents the adjustment coefficient in the pulse generator, in order to control the iterative speed and the segmentation accuracy effectively; $\overline{m}(n)$ expresses the average gray values of the segmented regions in each iteration. Furthermore, several other parameters have the same meaning as described in the original PCNN model [20,21]. In our scheme, the exponential decay mechanism is eliminated in the input field to simplify the framework of PCNN. The information of local gray-level changes is introduced into the proposed model, which brings improvement in the edges and details of the segmentation results. The improved expression of dynamic threshold E_{ij} no longer leads to periodic oscillations of segmentation during the iterations, and be used to obtain the final segmentation result in the way of gradual clustering. In the following sections, we will further discuss the setting methods of these parameters in the improved PCNN model.

2.1. Setting method of parameter $M_{ij,kl}$

In the input field, the weight matrix $M_{ij,kl}$ of feeding input F_{ij} plays a significant role which could transmit the gray-level information of the 8-point neighborhood to the central neurons pixel (i,j), and further expresses the local features of the infrared image. Therefore, the matrix weight $M_{ij,kl}$ could be utilized to enhance the local information and to suppress local infrared noises.

As is well known, local infrared noises are derived from the photoelectric transformation of infrared detector, the read-out circuits of IR camera and the fluctuation of photon in infrared background radiation, and consist of Gaussian noise, Poisson noise, multiplicative noise and salt-and-pepper noise [22]. Considering the characteristics of these noises, we construct the weight matrix $M_{ij,kl}$ from the anisotropic Gaussian kernels [23] as follows:

$$M_{ij,kl} = C_0 \cdot \frac{1}{2\pi\sigma^2} \exp\left(-\frac{1}{2\sigma^2} x^T H_{-\theta} \begin{bmatrix} \rho^2 & 0 \\ 0 & \rho^{-2} \end{bmatrix} H_\theta x\right), \tag{6}$$