Innovative Infrared Image Denoising: Enhancing Detail Preservation through Optimized Pulse Coupled Neural Network Parameters

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Abstract:

To address the issue of image blurring and the loss of edge information, as well as the common challenges of ambiguous targets and low contrast in infrared image preprocessing algorithms, this paper proposes a method for denoising infrared images using a simplified pulse-coupled neural network. The improved selection of neuron coupling strength, based on the gray value of neighboring pixels, enhances the denoising process. Furthermore, the computation of the threshold decaying exponent is simplified, making it dependent on the threshold amplitude, which can now be automatically optimized. Experimental results indicate that this method not only improves the efficiency of parameter optimization for the pulse-coupled neural network but also effectively filters out noise while preserving image details to the greatest extent possible.

Keywords:

Infrared Image; Noise Reduction Processing; Pulse Coupled Neural Network; NetworkParameter Optimization.

1. Introduction

Due to the characteristics of infrared image , in the transmission process, it is easy to be disturbed by the noise, and the noise reduction is the most important task of the image preprocessing[1].Use the traditional local mean based linear filter and the median filter based nonlinear filter for filtering. But in filtering noise, it will make the image of the details and texture information lost, which is not conducive to the late identification.The reason is that the pixels that are not interfered by noise are also processed when the traditional filter is to remove the noise signal. If it is able to identify and classify the pixels that are affected by the noise and the pixels that are not disturbed, then filter the pixels which are affected by the interference. So it can not only reduce the amount of computation, but also can maintain the image edge details of the information which can improve the efficiency of image recognition.

2. Pulse coupled neural network

Pulse coupled neural network (PCNN) was proposed by Eckhorn in 1990. It is based on the third generation of artificial neural networks, which are based on the synchronous pulse phenomena in the visual cortex of the cat. Compared to the traditional artificial neural network, it can better simulate the biological behavior [2-3]. In recent years, PCNN has been widely used in the field of image processing, such as noise reduction, segmentation, fusion, recognition and so on. PCNN uses the ignition mechanism to find the noise pollution point by judging the ignition state of the pixels in the neighborhood. Then, according to the type of noise, choose method of mean, median[4], the Fu matrix [5-6], Variable length [7], wavelet [8] and so on to deal with. This can have a certain purpose of filtering which is better than the traditional noise reduction methods.

The infrared image has the characteristics of non-obvious target and low contrast. Use PCNN for image denoising preprocessing, which has the advantages of no training and strong purpose**.**

PCNN is a development model of the cat visual cortex based on a nonlinear dynamic neural network, which is composed of many interconnected neurons. A PCNN neuron is composed of three parts: the receiving part, the modulation part and the pulse generating part, and the PCNN neuron model is shown in Figure 1. The original model equations are as follows:

$$F_{ij}[n]=e^{-a_F}F_{ij}[n-1]+V_F\sum_{kl}W_{ijkl}Y_{kl}[n-1]+I_{ij} \quad (1)$$

$$L_{ij}[n]=e^{-a_L}L_{ij}[n-1]+V_L\sum_{kl}W_{ijkl}Y_{kl}[n-1] \quad (2)$$

$$U_{ij}[n]=F_{ij}[n](1+\beta L_{ij}[n]) \quad (3)$$

$$Y_{ij}[n]=\begin{cases}1 & U_{ij}[n]>\theta_{ij}[n]\\ 0 & U_{ij}[n]\le\theta_{ij}[n]\end{cases} \quad (4)$$

$$\theta_{ij}[n+1]=e^{-a_\theta}\theta_{ij}[n]+V_\theta Y_{ij}[n] \quad (5)$$

In the above formulas, I_{ij} is an external excitation. $F_{ij}\left[n\right]$ represents the $\left(i,j\right)$ neurons of the n feedback input. $L_{ij}\left[n\right]$ is the $\left(i,j\right)$ neurons of the n connections from input. M_{ijkl} and W_{ijkl} represents neural $\left(k,l\right)$ and $\left(i,j\right)$ between F channel and L channel of the synaptic connection weights matrix. β is synaptic connectivity coefficient and $U_{ij}\left[n\right]$ is internal activities. $\theta_{ij}\left[n\right]$ $\left(i,j\right)$ $\theta_{ij}\left[n\right]$ is a dynamic threshold of $\left(i,j\right)$ neurons. α_F , α_L and α_θ are the decay time constants of the corresponding channels. V_F , V_L and V_θ are the corresponding amplitude coefficient $Y_{ij}\left[n\right]$ is neuronal $\left(i,j\right)$ n-th output and $Y_{kl}\left[n\right]$ in neuronal $\left(k,l\right)$ n-th output. It is known that the internal active item U_{ij} is the coupling product of the feedback input F_{ij} and the connection input I_{ij}, and the dynamic threshold θ_{ij} is compared with the later control neuron ignition output Y_{ij} .If a neuron ignition, the output of the pulse signal will be sent to the adjacent neurons, and in the neighborhood of its similar neurons will be ignited. They will emit a synchronous pulse signal to form the characteristics of the PCNN capture and synchronization pulse release. By using this characteristic to image processing, it can eliminate the gray level difference between the pixels in the neighborhood space, and then smooth the image to achieve the purpose of noise reduction.

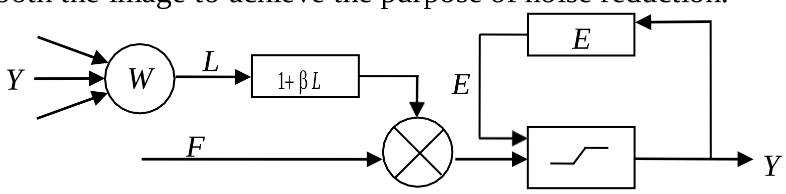


Fig.1 PCNN neuron model

3. Simplified PCNN model

In the practical application, the PCNN basic model has the characteristics of controllable parameters, complex setting, and mainly dependent on the experience value. On the basis of maintaining the important characteristics of the original model, some parameters are reduced, and then the simplified PCNN model is formed [9]. The neuron structure is shown in figure 2. The performance of PCNN isdirectly determined by the parameter selection, so the search for the optimal parameter becomes a very tedious and important work [10-11].In this paper, the parameters of PCNN simplified model are analyzed, which is helpful to improve the search efficiency of network optimization parameters.

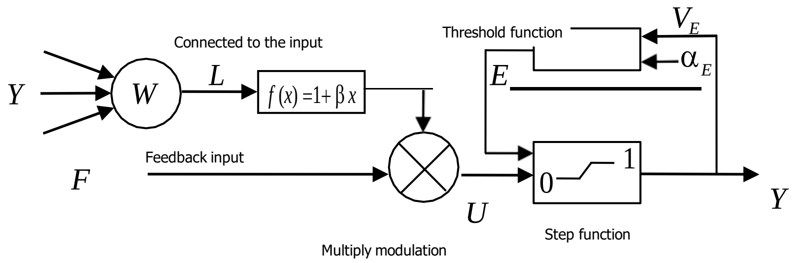


Fig. 2 simplified structure model of PCNN neurons

After the model is simplified, the model is described by the following mathematical equations:

$$F_{ij}[n] = I_{ij} \tag{6}$$

$$L_{ij}[n] = \sum_{kl} W_{ijkl} Y[n-1] \tag{7}$$

$$U_{ij}[n] = F_{ij}[n](1+\beta L_{ij}[n]) \tag{8}$$

$$E_{ij}[n] = \exp(-\alpha_E) E_{ij}[n-1] + V_E Y_{ij}[n] \tag{9}$$

The input neurons F_{ij} is external input excitation I_{ij} , that is, (i, j) pixel gray value, i.e.; L_{ij} , U_{ij} , Y_{ij} , E_{ij} are the neurons connected input and internal activities, pulse input and dynamic threshold; W_{ijkl} is connection of the weight coefficient matrix, β is the strength of neuronal connections; α_E and V_E respectively is the threshold of the attenuation index and amplitude.

4. Simplified PCNN application in infrared image noise reduction

The complete process of simplified PCNN infrared image noise reduction processing is shown in figure 3. According to the formula (6) ~ (9), the infrared image is calculated by iteration.

In the application of simplified PCNN model for processing infrared image noise reduction, from equation (6) ~ (10) can be seen, in the formula (6), the direct information of image is the pixel gray value of the image, that is, the parameter F, and no other parameters need to be determined;W_{ijkl} In formula (7), it is needed to determine the connection weight coefficient matrix. W_{ijkl} , for image processing ,W_{ijkl} take $[0.510.5;101;0.510.5]$ or $[0.10.50.1;0.5\,0\,0.5;0.10.50.1]$; in equation (8), it needed to determine neuronal connection strength values of β ; The parameters α_E and V_E affect the exponential change of the threshold E and the frequency of the oscillation of the neuron, which need to be determined in the formula (9), so finding the optimal value of the parameter β , α_E and V_E is the key to improve the performance of PCNN network.

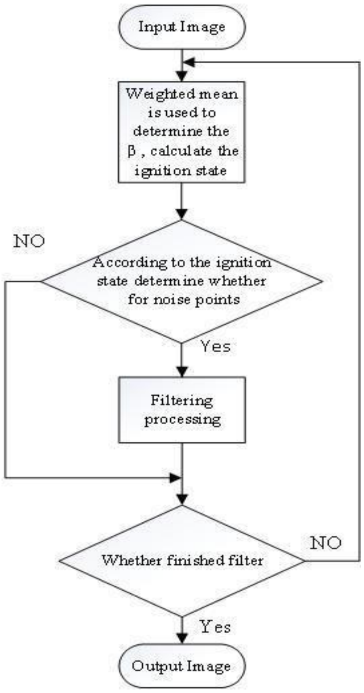


Fig. 3 flow chart of simplified PCNN filter

4.1 Determination of neuronal connectivity intensity β .

Because the strength of the connection strength parameter β represents the strength of the connection between the peripheral neurons and the neuron, when the other conditions are determined, the smaller the β , the better the denoising effect, the better the performance of image restoration.So the selection of its value is related to the specific application. Empirical value of β =0.1 or 0.01, in the processing of infrared image noise reduction, according to the characteristics of the infrared image, the selection method of β is improved, the fixed value is changed to the dynamic value associated with the surrounding pixel gray value.

Take the pixel as the center, to find the 3×3 neighborhood of the weighted mean value I_{kk} , weight W =[0.5 1 0.5;1 0 1;0.5 1 0.5], with the point of the pixel gray value I_{ij} minus I_{kk} and 255 for business, namely $\beta = (I_{ij} - I_{kk}) / 255$. And the mean value of the gray difference determines the size of the β , the greater the U_{ij} , the greater the β , which improve the ability to synchronize the ignition.

Thus, the noise points are selected and filtered. For edge pixels, a value filled method or truncation method can be used. In this paper, taking into account the infrared images taken with uninterrupted scanning mode, the rounding around images pixels will not seriously affect the recognition results.

4.2 Determination of threshold attenuation index α_E and amplitude V_E

The shock characteristic equation of PCNN neurons is as follows:

$$V_E \circ \frac{1}{e^{\alpha_E n}} = F \circ \ (1+ \ \circ e^{-\alpha_L nk} L) \tag{10}$$

Parameters n and k is the iteration cycle which take a positive integer. α_L is the constant time. L is the input connection. From formula (10), it can be seen that when the input image gray value of F increases, unchanged in α_E , then n should be reduced. This indicates that when the parameter A is determined, the oscillation period decreases with the increase of the pixel gray value. PCNN neurons use this characteristic to produce the corresponding oscillation frequency for different input of F, so as to realize the quantization value of input F.

Further simplification of the formula (11) can be written as follows:

$$\alpha_E = \frac{1}{n}\ln\left|\frac{V_E + F \circ (1+\beta L e^{-\alpha_L})}{F \circ (1+\beta L e^{-\alpha_L nk})}\right| \quad (11)$$

In practical applications, $\beta L e^{-\alpha_L nk}$ is a bounded function, which satisfies the $0 < \beta L e^{-\alpha_L nk} < \beta L$, and with the iteration number k close to the iteration period n, the PCNN enters the steady state. $\beta L e^{-\alpha_L nk}$ tends to be a constant, and C is used to express:

$$\alpha_E = \frac{1}{n}\ln\left|\frac{V_E + F \circ (1+c)}{F \circ (1+c)}\right|, 0 < c < \beta L \quad (12)$$

From the formula (12), it can be seen that in the β is determined, the value of α_E is dependent on the amplification factor V_E, and V_E is used in the same conditions from the initial value of 220 in accordance with the step size 10 increments. Computer experiments can be seen that the signal to noise ratio (signal to noise Ratio.SNR) curve of the effect of V_E change on image is shown in Figure 4, and the optimal value of V_E is obtained.

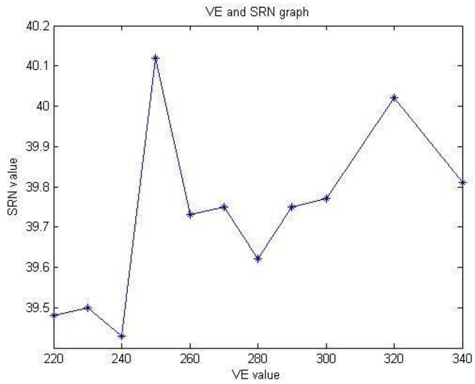


Fig. 4 SNR curves of different worth of V_E

5. Experiment and data analysis

Specific experimental procedure is as follows:

(1).Gauss noise with a variance of 0.01 and the salt and pepper noise with the noise density of 0.1 for the original image, interference noise image can be obtained.(Fig6 b, g, Fig7 b, g)

(2).The simplified PCNN model is initialized, and the values are as follows:

Connected weight matrix

$$\beta = (I_{ij} - I_{kk}) / 255$$

From different V_E to the image of the SNR curve, it can be seen that the infrared image effect is better when the V_E gives the value of 250, so VE=250.

.According to formula (13), it can be calculated to get $\alpha_E = 0.12$ The threshold attenuation index α_E varied from 0.02 to 0.6, The change curve of the noise image, the denoising image and the original image corresponding to the signal to noise ratio (SNR) and the peak signal to noise ratio (Signal to Noise Ratio Peak, PSNR) is shown in figure 5.it can also be seen that in the vicinity of 0.12, the curve has a cross so as to determine $\alpha_E = 0.12$.

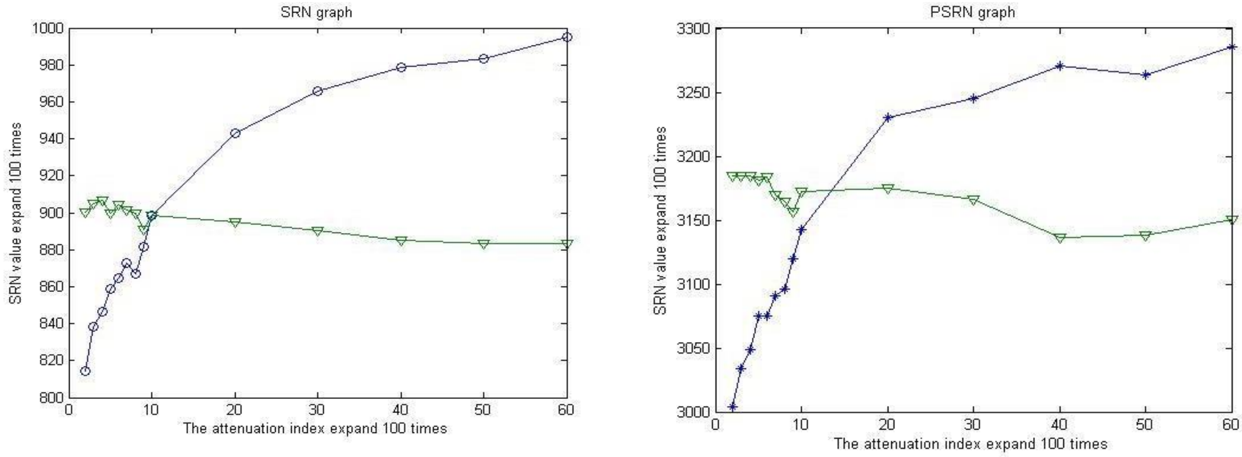
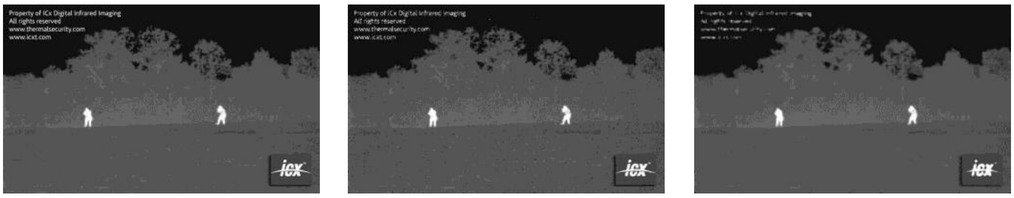


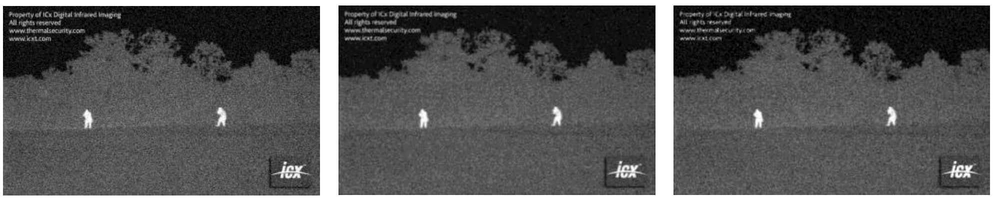
Fig. 5 the attenuation of threshold and the change of SNR and PSNR

(4).When the infrared image noise reduction processing, for added Gaussian noise and salt and pepper noise of infrared image (people) and infrared forest fire image (fire), respectively use the mean, median, traditional PCNN and simplified PCNN method and the comparison of filtering results with the original are shown in figure 6 and Figure 7.

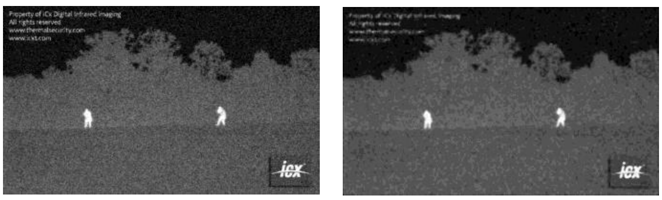
(a)The infrared gray artwork (b) Add salt and pepper noise figure (c) Salt and pepper 3x3 average filter



(d) Salt and pepper 3x3 median filter (e)Traditional PCNN filter salt and pepper (f) Modified the salt and pepper PCNN filter



(g)Add gaussian noise figure (h) Gaussian 3x3 average filter (i)Gaussian 3x3 median filter



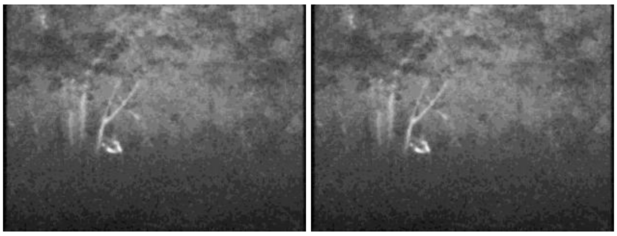
(j) Traditional gauss PCNN filter (k) Modified PCNN gaussian filter

Fig 6 infrared image (human) filter control chart

(a)The infrared gray artwork（b）Add salt and pepper noise figure (c) Salt and pepper 3 x 3 average filter

（d）Salt and pepper (e) Traditional PCNN（f）Modified the salt and
3x3 median filter filter salt and pepper pepper PCNN filter

(g)Add gaussian noise figure（h） Gaussian 3x3 average filter (i) Gaussian 3x3 median filter



（j）Traditional gauss PCNN filter (k) Modified PCNN gaussian filter

Fig. 7 image filtering control of infrared forest fire

.For the simplified PCNN of Gaussian noise and salt and pepper filtering effect, in addition to direct the human eye observation, also need to use quantitative evaluation. The peak signal-to-noise ratio (PSNR) is one of the commonly used parameters, the formula is as follows:

$$PSNR = 10\lg \frac{I_{\max}^2}{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(I_{ij} - Y_{IJ})^2} \quad (14)$$

In the above formula, M and N respectively represent the image number of rows and columns. $1 \le i \le M$, $1 \le j \le N$, I_{ij} is not affected by the noise pollution of the original image. Y_{ij} is the image after filtering.

For the image of added noise, mean filtered image, median filtered image, after the classic PCNN filtered image and improved simplified PCNN filtered image and the original image, PSNR values were calculated respectively. The calculation results are shown in Table 1.From the data results, it can be seen that in the infrared image noise reduction processing, the improved simplified PCNN filtering effect is better than the traditional filtering method.

Table 1 Infrared image denoising and fire PSNR value table

		Noise figure	3×3Mean filter	5×5Mean filter	3×3median filtering	4×4median filtering	Traditional PCNN filter	Improved PCNN filter
infrared	0.01Gaussian noise	22.4456	26.0257	25.0980	25.3727	24.5613	25.0892	25.8070
	0.1Salt and pepper noise	15.4366	22.7002	23.4877	27.8720	25.4162	28.9746	29.1866
Fire	0.01Gaussian noise	22.3448	29.2708	31.7897	28.1452	29.9477	26.6626	31.4382
	0.1Salt and pepper noise	15.8642	24.7087	27.8009	39.8832	36.4465	35.5947	40.6190

6. Conclusion

The improved simplified PCNN model is used to reduce the noise of infrared image. The calculation method and the fast determination of the optimal value of the strength parameters, the attenuation exponent and the amplitude of the connection are discussed, and the simulation is carried out in the Matlab environment.From the experimental results and PSNR data, it can be seen that the method in this paper is better than the traditional median, mean and PCNN filtering method.While filtering the noise, it is effective to protect the edge information of the image. How to combine PCNN with other excellent methods in filtering is to be further studied. At the same time, PCNN is a kind of non-learning neural network, which is lack of the ability to combine with the inherent characteristics of the image.And improving the adaptive ability is also a direction of development in the future.

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