Edge detection and location of seismic image based on PCNN

Li Lou\textsuperscript{1,}\textsuperscript{a}, XiangWei Chang\textsuperscript{2,}\textsuperscript{b}

\textsuperscript{1}School of Computing, Xi’an Shiyou University, Xi’an, Shaanxi, China
\textsuperscript{2}School of Computing, Xi’an Shiyou University, Xi’an, Shaanxi, China
\textsuperscript{a}986325351@qq.com, \textsuperscript{b}2606461383@qq.com

Abstract. The discontinuous features in seismic data usually correspond to different geological edge information. Effective processing of these seismic data can help us make correct geological interpretations. In this paper, we apply coherent slices to detect and locate the boundary of fault polygons and propose a method for boundary detection and localization of seismic images based on PCNN. In image edge detection, the basic PCNN needs to adjust many parameters. This paper aims at this problem to improve the basic PCNN model, we simplify the feedback input and pulse input, only retain the external input stimulation and the connection domain external neuron stimulation, reduce the parameters, and simplify the calculation. Optimize parameters such as internal activity link coefficients, dynamic thresholds, and cycle times to improve interpretation efficiency and accuracy. Experiments show that the method used in this paper has good practicability and can effectively realize the fault polygons detection and positioning of coherent slices.

1. Introduction

In recent years, PCNN has been widely used in image processing. Literature\textsuperscript{[1]} uses PCNN's ignition propagation characteristics and image gray-scale statistical characteristics for image edge detection. This method effectively realizes image edge detection. However, due to the huge parameters of the PCNN model, the reasonableness of its model parameters is a difficult point, and there are difficulties in the adaptive threshold setting and the condition determination of the iteration termination. In the literature\textsuperscript{[2]}, how to choose PCNN parameters in this model algorithm is studied, and the parameters are compared and selected. The results show that the set parameter values have a better edge detection and positioning effect. In the literature\textsuperscript{[3]}, the ignition characteristics of PCNN neurons with or without coupling are studied and analyzed in the time domain, and simplifies the grid parameters of PCNN, and the image edge detection is performed through the adaptive setting method of parameters. In literature\textsuperscript{[4]} proposed the automatic setting algorithm of PCNN parameters of the clone selection algorithm, which gave full play to the optimization characteristics of the clone selection algorithm and improved the application effect and efficiency of PCNN. In Literature\textsuperscript{[5]}, a hybrid optimization method of self-tuning pulse-coupled neural network parameters based on the harmony search algorithm and simulated annealing idea is proposed for edge detection of sintered particle images, and the parameters of the model are set in an adaptive manner. The method can effectively detect the edge of the sintered particle image.

In this paper, we apply coherent slices to extract the boundary of fault polygons and propose a PCNN-based seismic image boundary detection and location method. Due to the large number of parameters in the PCNN model, in this paper, we simplify the PCNN model, and only retain the external input stimulation of the feedback input, and the external neuron stimulation of the connection domain is
retained in the pulse input, which reduces the parameter selection and simplifies the calculation. And optimize the selection of parameters to improve the efficiency and accuracy of interpretation. And at the end, we use the edge continuity index and information entropy to evaluate and analyze the edge detection effect.

2. PCNN seismic image edge detection and positioning

Pulse coupled neural network is a new type of neural network, which can be widely used in image processing and recognition, and decision optimization. Its pulse propagation characteristics can be used for image edge detection and positioning.

2.1. PCNN model

PCNN is a single-layer two-dimensional locally connected feedback network composed of several neurons. Each neuron includes receiving, modulation and pulse generation. The receiving part includes the feedback input \( F_{ij} \) and the connection input \( L_{ij} \) of the neuron \( i,j \), the modulation part is the internal activity item \( U_{ij} \), the pulse generation part is the dynamic threshold \( E_{ij} \) and the pulse output \( Y_{ij} \). The mathematical model is as follows:

\[
F_{ij}(n) = \exp(-a_j)F_{ij}(n-1)+V_F \sum M_{ik} Y_k(n-1)+S_{ij}
\]

\[
L_{ij}(n) = \exp(-a_i)L_{ij}(n-1)+V_L \sum W_{ijkl} Y_k(n-1)
\]

\[
U_{ij}(n) = F_{ij}(n)(1+\beta_j L_{ij}(n))
\]

\[
Y_{ij}(n) = \begin{cases} 1 & U_{ij}(n) > E_{ij}(n-1) \\ 0 & \text{other} \end{cases}
\]

\[
E_{ij}(n) = e^{-a_E} E_{ij}(n-1)+V_{ij} Y_{ij}(n)
\]

2.2. PCNN Simplified model

In image processing, PCNN need to adjust many parameters, including \( V_F, V_L, \alpha_i, \) etc., which will be more complicated in actual operation. Therefore, improve the basic PCNN model is simplified, simplify the feedback input \( F_{ij} \) and pulse input \( L_{ij} \), and the formula (1) (2) is adjusted as follows (6) and (7):

\[
F_{ij}(n) \approx S_{ij}
\]

\[
L_{ij}(n) = \sum_{kl} W_{ijkl} Y_k(n-1)
\]

The simplified PCNN model still has the basic characteristics of PCNN's threshold adjustable, coupling link, dynamic threshold, and time attenuation. The setting of link coefficient \( \beta_{ij} \), dynamic threshold \( E_{ij} \) and number of iterations \( n \) affect the edge detection effect of the image.

2.3. Image edge detection and positioning based on PCNN

When PCNN is used for image edge detection, the neurons correspond to the pixels of the image one-to-one. The gray value of the pixel is input through the channel \( F_{ij} \) of the corresponding neuron. The output of the neuron in the 3*3 field enters the \( L \) channel of the neuron. The neuron's output includes two states of ignition or non-ignition.

When a neuron randomly has a neuron in its 3*3 field in a firing state, the neuron will also fire, and the output pulse of the neuron will begin to transmit. When PCNN detects the edge of a binary image, if the pixel value is 1, it corresponds to the background, the pixel value is 0 to indicate the target. the neuron corresponding to the background will ignite first, and the neuron corresponding to the target will not ignite, Record the ignition state of each neuron to obtain the ignition binary image \( A_{ij} \). Continue to let the
pulse emitted from the background pass a pixel distance to obtain the ignition binary image $A_1$. XOR processing the binary image $A$ and $A_2$. And obtain the edge of the image $E$. The edge width is the distance of one pixel. The image edge detection algorithm process based on PCNN is as follows:

1. The matrix $F$ is used to store the coherent slice binary image, $E$ representing the detection result, $Y$ representing the output of the neuron, $U$ representing the internal activity item, $L$ representing the connection input, $E_{ij}$ representing the dynamic threshold. The matrix dimensions of $E$, $Y$, $L$, $U$ and $\theta$ are the same $F$, so that the pixel value in these 5 matrices is 0. The dimension of the adjacent pixel matrix $K$ of the neuron is $3*3$, set the link strength, and $n = N+1$, $N$ represents the edge width of pulse propagation.

2. According to formulas (3), (4), (7), we obtain the values of matrix $U$, $Y$, $L$. When the element value of $U$ is 1, we calculate the element value of $E_{ij}$ by formula (5).

3. If $n = N+1$, then make $n = n-1$ and go to step (2) to continue execution. Otherwise, if a certain element value is 1, set the value of the corresponding element in $E$ to 1.

4. If $n \neq 1$, go to step (2) to continue execution, if $n = 1$, output the result matrix $E$.

3. PCNN model parameter optimization

The simplified PCNN retains the characteristics of the basic PCNN, and the setting of key parameter values such as the link coefficient $\beta_{ij}$, the dynamic threshold $E_{ij}$ and the number of iterations $n$ affects the edge detection results of the image.

3.1. The choice of connection strength $\beta_{ij}$

In a single neuron, multiply and modulate the feedback input $F$ and the connection input $L$, for different link coefficient values $\beta_{ij}$, when the neurons are weakly connected, $\beta_{ij} < 0.1$, the set value is 0.001, as shown in Figure 3 and Figure 4. When there is a strong connection between neurons, that is $\beta_{ij} > 10$, the set value is 1000, as shown in Figure 5 and Figure 6. The comparison found that the edge detection of the image can be completed, and the strong and weak links have no major impact on the edge detection and positioning results.
3.2. The selection of dynamic threshold $E_y$

Set the brightness value range of the image to $[a, b]$, $0 < a, b \leq 255$, the threshold $a \leq E_y \leq b$.

(1) When the brightness value range of the image is $[1, 10]$, $\beta_y = 10$, the edge detection positioning effect is shown in Figure 7 and Figure 8.

$$1 \leq E_y \leq \min[10, 1 \times (1 + \beta_y)] = \min(10, 11) = 11 \quad (8)$$

(2) When the brightness value range of the image is $[100, 200]$, $\beta_y = 0.4$, the edge detection positioning effect is shown in Figure 9 and Figure 10.

$$1 \leq E_y \leq \min[255, 254 \times (1 + \beta_y)] = \min(255, 254.254) = 254.254 \quad (9)$$
(4) When the brightness value range of the image is $[254,255]$, $\beta_{ij} = 0.001$, the edge detection positioning effect is shown in Figure 11 and Figure 12.

$$1 \leq E_{ij} \leq \min(255, 254(1 + \beta_{ij})) = \min(255, 254.254) = 254.254$$

(10)

When the brightness value range of the image is between $[100, 200]$, that is $\beta_{ij} = 0.4$, $E_{ij} = 140$, the image detection effect is the best.

3.3. The Selection of the number of iterations $n$

In the process of PCNN image edge detection, the pulse propagation distance $N$ is the width of the edge pixel of the image, and the number of iterations $n$ and pulse propagation distance $N$ is expressed as $n = N + 1$, when the pixel value of the image edge width is 1, then the number of iterations $n = 2$.

When $n = 2$, as shown in Figure 13 and Figure 14; $n = 3$, as shown in Figure 15 and Figure 16; $n = 4$, as shown in Figure 17 and Figure 18.
3.4. Analysis of simulation test results

This article draws on the methods in literature\(^7\) to evaluate and analyze the test results. The edge of the image is composed of \(n\) segments of continuous small edges, \(C_i = \{(x_i', y_i'), (x_{i+1}', y_{i+1}') , \ldots , (x_n', y_n')\}\), representing the edge sequence of any small segment of edges, and the center coordinates of the edges are expressed as \((x_i', y_i')\):

The distance from the pixel coordinate \((x_i', y_i')\) of the edge to the center \((x_i, y_i)\) of the edge is expressed as:

\[
d_i' = |x_i' - x_i| + |y_i' - y_i|
\]  

(11)

\(D\) represents the distance, the continuity index from \(E(x_i', y_i')\) to the edge of the \(i\) th segment is:

\[
c_i^c = \begin{cases} d_i' / D, & d_i' < D \\ 1, & d_i' \geq D \end{cases}
\]

(12)

\(SC^c\) represents the continuity of the edge, \(C^c\) represents the sum of the continuity index of a segment of edge pixels:

\[
SC^c = S(C^c) = 2 \times \left( \frac{1}{1 + \exp(-C^c / \alpha)} - 0.5 \right)
\]

(13)

Where \(\alpha = \min(n, m) / 20\), the continuity index of the edge is expressed by continuity weighted calculation:

\[
C_{idx} = \frac{\sum (n_i \times SC^c)}{\sum n_i}
\]

(14)

The range of \(C_{idx}\) is \([0, 1]\). The larger the value, the better the edge continuity in the image. Table 1 is the edge continuity index analysis of the edge detection results.
Table 1: Edge detection positioning result analysis

| Detection algorithm | Edge pixels | Edge segments | Continuity index | Detection time (s) | Information entropy (bit) |
|---------------------|-------------|---------------|------------------|--------------------|--------------------------|
| Roberts             | 28187       | 178           | 0.720            | 0.524              | 0.4062                   |
| Pewitt              | 29461       | 194           | 0.748            | 0.375              | 0.4175                   |
| Sober               | 27297       | 157           | 0.705            | 0.314              | 0.4188                   |
| Log                 | 26468       | 140           | 0.845            | 0.434              | 0.4505                   |
| Canny               | 28254       | 126           | 0.912            | 0.314              | 0.4157                   |
| PCNN                | 29640       | 114           | 0.936            | 0.906              | 0.8048                   |
| Text method         | 29813       | 109           | 0.947            | 0.682              | 0.8765                   |

| Detection algorithm | Edge pixels | Edge segments | Continuity index | Detection time (s) | Information entropy (bit) |
|---------------------|-------------|---------------|------------------|--------------------|--------------------------|
| Roberts             | 19874       | 137           | 0.682            | 0.589              | 0.3113                   |
| Pewitt              | 20485       | 127           | 0.712            | 0.625              | 0.3770                   |
| Sober               | 19987       | 105           | 0.697            | 0.547              | 0.3309                   |
| Log                 | 20808       | 119           | 0.734            | 0.611              | 0.3396                   |
| Canny               | 21597       | 108           | 0.897            | 0.620              | 0.5089                   |
| PCNN                | 21682       | 104           | 0.916            | 1.287              | 0.7654                   |
| Text method         | 21713       | 97            | 0.924            | 0.924              | 0.8197                   |

Through the comparison and analysis, because different edge detection positioning methods are affected by discrete points and their own detection principles are different, there are differences in the number of edge pixels. It can be seen from Table 1 that the difference is within a reasonable range. The comparison of methods will not have a big impact. In the case that the total number of edge pixels is not much different, the experimental data shows that the stronger the edge continuity of edge detection positioning, the fewer the number of edge segments, the better the continuity of the edge segments, and the greater the continuity index. It can be seen from the detection results that the edge continuity index of the method used in this paper is relatively largest, and the continuity of the edge is the strongest, and the image edge detection effect is the best. When the edge pixels are missed, the information entropy of the edge image will be smaller. From the experimental data in Table 1, it can be seen that the information entropy value of our method is relatively large, and the missed detection rate is lower, which is better than other edge detection positioning methods, image edge detection and positioning results are the best.

4. Conclusion

In this article, we apply coherent slices to detect and locate the boundary of fault polygons and propose a method for boundary detection and location of seismic images based on PCNN. In image edge detection, the basic PCNN needs to adjust many parameters. This article addresses this problem to improve the basic PCNN model. Only retain the external input stimulus of the feedback input and the external neuron stimulus of the connection domain in the pulse input, which reduces the parameter selection and simplifies the operation. Optimize the selection of parameters such as internal activity link coefficient, dynamic threshold and cycle times, analyze the link coefficient through the strong and weak connections of the neuron, and select the extreme value of the link coefficient to obtain a reasonable value of the link coefficient. According to the link coefficient, set the dynamic threshold to obtain the best dynamic threshold, perform multiple numerical comparisons on the number of iterations, thereby improving the efficiency and accuracy of edge detection and positioning. And use the edge continuity index and information entropy to evaluate and analyze the edge detection and positioning effect. Experiments show that the method used in this paper has good practicability and can effectively realize fault polygons detection and positioning of coherent slices.
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