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Research on the improvement of image edge detection algorithm based on artificial neural network

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ABSTRACT

Image edge detection is an essential basis of computer vision that has made rapid progress these years. Given the importance of the edge detection and the maturity of ANN (artificial neural network), we provide a research paper on the algorithms of image edge detection based on ANN. Firstly, we review the classic methods of edge detection and introduce some new methods proposed these years. Secondly, the foundations of ANN are briefly introduced. Subsequently, we present a traditional edge detection method based on ANN and summarize some disadvantages of this method. Finally, a new edge detection method based on ANN and parallel computing is put forward. The new method is superior to the old one in the efficiency and accuracy of detection.

1. Introduction

Image edge detection plays an important role in many scopes, such as image segmentation, pattern recognition and computer vision. It is also a problem which does not have a perfect solution. The solution of this problem has a positive role in promoting the development of feature extraction, image understanding and target recognition. The traditional operators of image edge detection are based on the gradient mostly, such as the Roberts operator, the Prewitt operator, the Sobel operator and the LOG operator (Laplace of Gauss). These operators can detect the edge roughly, but the detection ability is not strong.

In 1986, John Canny proposed three criteria of image edge detection: (i) high the signal-to-noise ratio; (ii) better positioning performance; (iii) Uniqueness of Response. On the basis of these criteria, a famous operator called Canny is obtained. To some extent, the detection result of Canny is better than that of the traditional operator.

The operators mentioned above are called classic operators. Though these classic operators are simple and convenient, they can only be applied to some finite edges. They have the problem of poor self-adaptability and sensitivity of noise. To different images, the same classic operators always have different results. The optimal model is different for different situations.

With the increasing requirements of the accuracy of algorithms in the image processing fields, some intelligent algorithms are used, such as artificial neural network, Genetic algorithm, ant colony optimization and Particle Swarm Optimization. Especially in 1990s, a huge success is achieved in the application of artificial neural network in the edge detection fields. Neural network is suitable for the field that cannot be modeled by the classic operators. It learns from samples, builds the model by itself. That is to say, the corresponding relation between the physical change of image edge and local spatial brightness in the image can be solved by sample set of the network training.

Although the neural network has the above mentioned advantage in the edge detection of image, the difficulty of choosing the image window size, the number of neurons and the number of network layers limit the development of it in the edge detection. When the image or the number of neurons is large, the amount of calculation will be great. We improve the algorithm of edge detection based on neural network to enhance the precision and efficiency. The new algorithm takes advantage of parallel computing and dynamic window.

Here is the structure of the paper. Section 2 introduces some classic edge detection operators and some recent research hotspots briefly. Elementary knowledge of artificial neural network is described in Section 3. Section 4 introduces the traditional edge detection algorithm based on artificial neural network and the improvement of it. Section 5 presents the comparative experiments

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between the traditional algorithm and the improved technique. Section 6 gives the analysis and conclusion.

2. Some edge detection algorithms

2.1. Algorithms based on gradient

The gray change of pixels around the most common edge presents the shape of a ladder or the shape of pulse. From the first-order derivative and the second derivative of these shapes, it can be drawn that the points of the edge appear in the maximum or minimum position of these derivatives. It may also occur in the zero position of these derivatives. Based on the above theory, researchers have proposed a gradient operator based on the first derivative, as follows:

$$G[f(m,n)] = \left[\left(\frac{\partial f}{\partial m}\right)^2 + \left(\frac{\partial f}{\partial n}\right)^2\right]^{1/2}$$

where $f(m, n)$ represents the gray of the pixel (m, n). By taking appropriate threshold T, the image edge can be judged. If $G[f(m, n)] > T$, the pixel(m, n) is the point of edge. For digital image, derivatives can be approximated by differential, partial derivative can be expressed as:

$$\frac{\partial f}{\partial m} = f[m+1,n] - f[m,n]\frac{\partial f}{\partial n} = f[m,n] - f[m,n+1]$$

The image can be regarded as a collection of discrete points. In order to reduce the amount of calculation, some operator templates are used to match with the image, replacing the above calculation. The most common operator templates are Robert operator, Sobel operator and Prewitt operator template, as follows:

$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

Robert operator

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Sobel operator

$$\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Prewitt operator

The edge got from the first-order derivative operator is always blur and coarse, so researchers have proposed the Laplasse operator based on second order derivative, as follow:

$$\nabla^2 f = \frac{\partial^2 f}{\partial m^2} + \frac{\partial^2 f}{\partial n^2}$$

where the second order derivative can be replaced by differential as:

$$\begin{aligned} \frac{\partial^2 f}{\partial m^2} &= (f[m,n+1] - 2f[m,n]) + f[m,n-1]\,\frac{\partial^2 f}{\partial n^2} \\ &= (f[m+1,n] - 2f[m,n]) + f[m-1,n] \end{aligned}$$

The second order method have higher Positioning accuracy than the first order one, but it strengthens the noise in the image.

2.2. Canny algorithm

In 1986 Canny put forward the optimization algorithm of the edge detection. He thought that an excellent edge detection operator should have three characteristics:

1) The signal-to-noise ratio must be high. The point of non-edge should not be detected as the point of edge.
2) The positioning performance must be improved. The edge point detected by the algorithm must be very close to the actual one.
3) Each edge point must have a unique response.

According to these the criteria, the implementation of Canny operator is as follow.

1) The original image is smoothed to remove noise by Gauss filter.
2) Calculate the gradient magnitude and direction by the first order partial derivative.
3) Conduct nonmaxima suppression of gradient magnitude.
4) Detect and connect edge with the two thresholds.

The Canny operator has better capability of edge detection and locating ability. It also has strong anti noise ability. In Section 5, the edge obtained from Canny operator will be used as the sample for neural network training.

2.3. Algorithms based on Fuzzy Theory

There are many events and phenomena, including image, that are fuzzy, cannot be simply classified as 0 or 1. It makes researchers seek to establish a suitable model to describe fuzzy things. In this situation, Fuzzy Theory has emerged to meet the requirement.

The basic idea of edge detection based on Fuzzy Theory is mapping the image from spatial domain to fuzzy feature domain through membership function firstly. Secondly, fuzzy is enhanced in order to enhance gray contrast of pixels around the edge point. Then image is transformed from fuzzy domain to spatial domain through inverse transformation of the membership degree matrix. Finally, detection of edge will be performed.

This method can separate the object from the background effectively, but the matrix calculation is complex and the anti noise performance is poor.

2.4. Algorithms based on multi-scale

Due to the physical, illuminating and other reasons, each edge in an image is usually produced in different scales. These different edges cannot be correctly detected by a single scale edge detection operator, so the edge detection method applying multiple scale attracts more and more attention. Multiscale edge detection method detects edge in different scale space, then synthesize the output to obtain the ideal edge.

3. Artificial neural network

There are many neurons which constitute network to store and process information in the brain,. Artificial neural network is a special network which simulates the way the brain works. Neural network is a nonlinear system that is composed of many simple computing element. In a certain extent, it imitates the processing and storing information function of the human nerve system. Due to its unique structure, neural network is expected to solve what cannot be solved by the traditional methods.

3.1. The neuron model

The neuron of neural network is the simulation and simplification of the neuron of human brain. A classical neuron model is

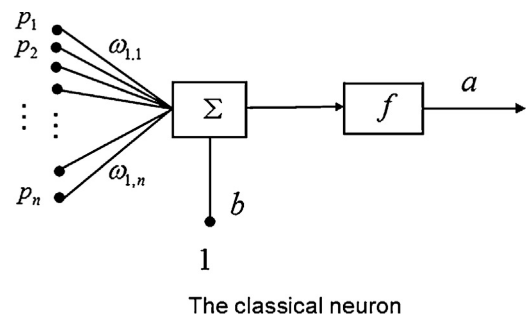

Fig. 1. Structure of the classical neuron.

mainly composed of the following five parts. The structure can be expressed as shown in Fig. 1.

(1) Input
$p_1, p_2, p_3, \ldots, p_n$ are representatives of n neuron inputs.

(2) The weights and threshold of network
$\omega_{1,1}, \omega_{1,2}, \omega_{1,3}, \ldots, \omega_{1,n}$ are representatives of network weights which represent connection strength between neurons and inputs. b is the threshold of network which can be regarded as a weight of a constant input 1.
Because both network weights and threshold are adjustable, neurons and even neural network are able to show some characteristics. Therefore, the tunability of neural weights and thresholds is the basic characteristic of neural network learning ability.

(3) The summation unit
The summation unit performs weighted sum of the input signals, as follow:

$$n = \sum_{i=1}^{n} p_i \times \omega_{1,i} + b$$

(4) The excitation function
f represents the excitation function which is used to make functional operation on the results of the summation unit. Several typical neurons excitation function are threshold function, linear function, logarithmic Sigmoid function and tangent Sigmoid function.

(5) Output
Through the above calculation, output can be obtained as:

$$a = f\left(\sum_{i=1}^{n} p_i \times \omega_{1,i} + b\right)$$

3.2. The structure of neural network

Neural network is composed of some layers. These layers consist of some neurons. The structure can be expressed as shown in Fig. 2.

It is well known that the larger the number of layer and neuron is, the better the adaptability and learning ability will be. But the amount of calculation will be great so that the efficiency will be low. Therefore, the choice of the number of layer and neuron is very important. The most common structure has three layers – the input layer, the hidden layer, and the output layer.

3.3. Learning and training of neural networks

The process of learning and training is a process of changing weights and thresholds constantly. Different weights and

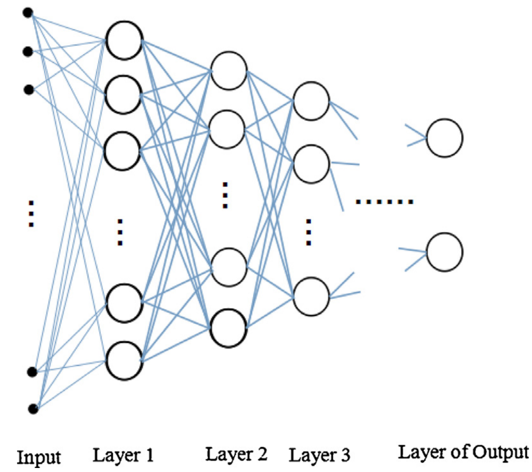

Fig. 2. Structure of a neural network.

thresholds lead to different outputs. If the outputs are not desired, the weights and thresholds will continue to change.

Because of the structure and the learning ability, neural network is suitable for those problems that cannot be modeled simply.

4. The traditional edge detection algorithm based on artificial neural network and the improvement of it

4.1. The traditional method

4.1.1. The selection of the structure

The traditional method generally uses three layers network. It includes input layer, hidden layer and output layer.

4.1.2. The number of input neurons, hidden neurons and output neurons

When an image waiting to be detected is chosen, a $N \times N$ fixed size window will be used to choose the pixels which are sent to the neural networks. The window will move on the image, and the center of the window will go through each pixel in the image. The number of input neurons is equal to the number of the pixels in the window. In this paper, we choose 5×5 fixed size window, so the number of input neurons is 25.

So far, there is no clear rule to determine the number of hidden layer neurons. In general, the number is determined by empirical formula, as follow:

$$n_1 = \sqrt{m + n} + \alpha$$

where n_1 represents the number of hidden layer neurons. m is the number of input neurons, and n is the number of output neurons. α is an integer between 1 and 10.

In this paper, the number of output neurons is 1, and α is 3. According to the above formula, n_1 is 8.

4.1.3. The learning sample

The learning sample is generally a high-precision edge binary image. Because the precision of Canny Algorithm is higher than some classic algorithms, the edge image obtained by Canny Algorithm is used as the learning sample in this paper.

4.1.4. The learning method

This paper adopts back-propagation network. The BP (back-propagation) method consists of two parts. The first part is the forward propagation of information, and the second part is the back propagation of error. In the forward propagation, the input information is transferred to output layer by layer. The state of each layer

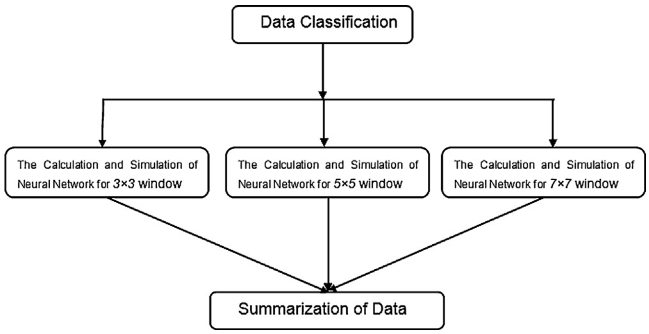

Fig. 3. Parallel process of the neural networks.

only affects the state of the next layer. If the output is not desired, the error will be calculated. The error will be back-propagated to the previous layer. According to the error, the weights and threshold of every layer will be adjusted until the desired goal is obtained.

4.2. The disadvantages of traditional method

The disadvantages of traditional method are shown as follows:

1) Because of the complexity of the neural network, this method usually takes a lot of time, especially when there are many neurons. The more neurons are used, the better the performance of neural network will be, but the efficiency will be low. Such contradictory cannot be solved easily.
2) The detection ability should be improved. Some edge points detected by Canny operator cannot be detected by this method. This is because the size of detection window is fixed.

The experiment of this method will be conducted in Section 5.

4.3. The improvement

4.3.1. Dynamic window

Since the surrounding of each pixel is different, the size of the detection window should be adjusted with the changes of the surrounding. That is to say, the size of the window should not be fixed, and it should be dynamic changes as needed. The criterion that is supposed to be used to change the size of the window is not clear. In this paper, we consider using the size of the standard deviation to control the size of the window. There are three different size windows, respectively 3×3, 5×5, 7×7. For every pixel in the image, standard deviations of the gray of all the pixels in these three different windows are calculated by fixing the pixel in the center of the windows. Then, the size of these three standard deviations are compared. If the standard deviation of 3×3 window is the largest, we choose 3×3 window, and soon. Therefore, there are three kinds of input: the 3×3 window, the 5×5 window and the 7×7 window.

4.3.2. Parallel computing

Parallel computing separates problem into parts. Each part is calculated by an independent processor. These calculations are parallel in time. Therefore, it can save time and improve efficiency. In this paper, according to dynamic window, the pixels in the image is divided into three categories. Each kind of pixel is processed by an independent neural network. The three neural networks are parallel processed in space. After calculation, the three kinds of input are simulated respectively. Finally, the simulation results of these three input are aggregated together. This process can be expressed as shown in Fig. 3.

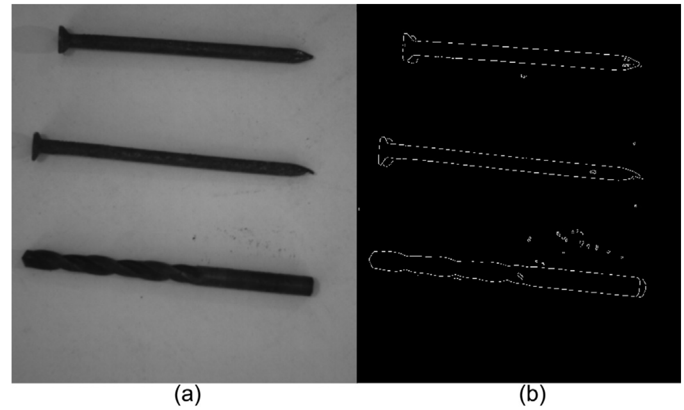

Fig. 4. (a) The image to be detected, (b) the learning sample.

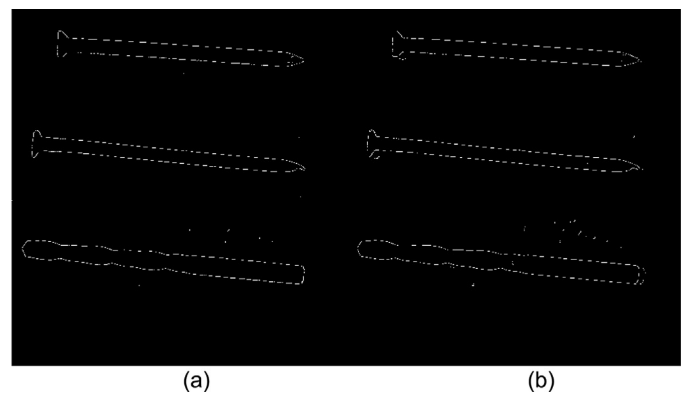

Fig. 5. (a) The image obtained by traditional ANN method, (b) the image obtained by improvement method.

5. Experiments

In this section, we will do a comparative experiment. In the experiment, the same image is processed respectively by traditional artificial neural network method and the improvement method. Then the processing effect between these two methods are compared. The experiment is done on Matlab (version number r2012a).

The image to be detected and the learning sample are shown in Fig. 4. Notably, the learning sample is the edge image obtained by Canny Algorithm.

The edge image obtained by traditional artificial neural network method and the edge image obtained by the improvement method are shown in Fig. 5.

This experiment is performed ten times. we find that the time required for the latter method is roughly half that of the former.

6. Analysis and conclusion

By observing the images in Section 5 carefully, we find that the simulation effect of the improvement method is better than that of the traditional ANN method. The edge image obtained by the improvement method is more like the learning sample. Some edge pixels in the learning sample that do not appear in the image obtained by traditional method, but appear in the other one. This suggests that the improvement method improve the simulation ability of traditional artificial neural network.

Pixels in the image should not be processed by a same artificial neural network. What is more, it is not right that the larger the size of the neural network is, the better the calculation result will be. For some pixels, small-scale artificial neural is the most suitable, while for other pixels, large-scale artificial neural is preferred. The key is how to distinguish between these pixels. The improvement method divided the pixels into three categories according to standard deviation. Three different scale neural networks are used to analysis the different pixels. Although standard deviation may be not the best classification standard, but this method can improve the simulation ability of the neural network to a certain extent. In future, our study will focus on finding the best classification standard.