Overview of Image Denoising Based on Deep Learning

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Abstract. With the advent of the artificial intelligence era, deep learning technology is widely used in various fields, showing a good advantage in image noise reduction. In order to let more scholars understand the progress of machine learning in the field of image noise reduction, the research on machine learning in image denoising is reviewed. This paper mainly introduces three kinds of models, such as convolutional neural network, pulse coupled neural network and wavelet neural network, which are commonly used in image denoising. The nonlocal mean noise reduction method based on machine learning is described as a concrete case. The purpose of the article is to clearly understand the latest developments in deep learning in the field of image noise reduction.

1. Introduction

In recent decades, image denoising technology has been rapidly developed, and a variety of traditional denoising algorithms have been produced and applied well. For example, Gaussian method [1], mean method [2], median method [3], non-local mean method [4]. Although these classical algorithms are widely used, but there are also problems in maintaining image structural integrity, further research on image denoising techniques is needed. Different mathematical theory knowledge creates different algorithms. When new mathematical knowledge is applied to image denoising, the corresponding image denoising research will enter a new stage. The popular neural network technology has been applied in the field of image noise reduction in recent years, and has achieved good denoising effect. With the development of artificial intelligence, technologies such as neural network deep learning have been widely applied to various fields. At the same time, image noise reduction technology has been further developed. Then some image denoising methods based on deep learning have emerged. For example, [5]Li Chuanpeng's image denoising deep neural network in the literature, [6]Zhang Wenxing's image denoising method pulse-coupled neural network in the literature, and the PCNN based on Zou Wenjie in the literature [7] Research on image denoising algorithms in networks.

2. Types of neural networks commonly used in image noise reduction

2.1. Convolutional neural network

Convolutional neural network contain Feature acquisition section and Feature corresponding part structure using sigmoid colon as the activation function, in order to maintain the displacement invariant convolutional neural network structure diagram as follows.
As can be seen from the figure, the convolution operation is performed on the input sample image, and then the offset is applied to generate four corresponding feature maps on the $C_1$ layer, and then every four pixels in the map are summed, plus weights and sums. The offset is obtained by the ReLU activation function to obtain the feature maps of the four $S_2$ layers, after filtering, it reaches the $C_3$ layer, and $C_3$ uses the same processing method as the $C_2$ layer to reach $S_4$. and finally the pixel values are rasterized into a vector input. The neural network gets the output result value. In the literature[8], Ren Jing gave a deep network based on convolutional neural network in the research of image denoising algorithm of basic convolutional neural network. This network is different from traditional neural network, which consists of four sub-networks. The input image of the network is subjected to multiple convolution operations, and the input image is filtered multiple times to obtain a feature map. Finally, the feature maps are fully connected to obtain an output image. In[9], Wang Jing et al. proposed a new improved method for noise images. Different from traditional convolutional network, the structure she gave only contains the convolutional layer and does not contain the sampling layer. The denoising process is The three processes of image block extraction, nonlinear mapping and image reconstruction directly realize the mapping of noise images to clean images. In[10], Wang Chun et al. proposed a deconvolution algorithm based on real scene image convolutional neural network. This method is constructed by constructing a new noise-free image data set and inputting it into the convolutional neural network. Simulated annealing algorithm improves training rate and establishes denoising model to realize real scene image denoising. In [11],Lei Junfeng point out an image mixing noise removal algorithm based on convolutional neural network. The network uses a 9-layer convolution network through feature extraction, dimensional contraction, nonlinear mapping, dimensional magnification and image. Reconstruction trains the noise image to get the final model. In the literature[12], Zhang Yungang Point out an image denoising method use convolutional neural network for the poor visual effect of low-dose computed tomography images. The network introduced batch normalization and then learned images. The mapping function between the two uses the cavity convolution to increase the receptive field.

2.2. Pulse coupled neural network

Eckhorn proposed a pulse-coupled neural network in the 1990s, which is a network structure use the cat's view principle[13]. There is a big difference compared to traditional neural networks. Because PCNN does not need learning and draw valid information from intricate backgrounds, with the characteristics of sync pulse and entire join, its operating mechanism is similar to that of human visual systems.
$I$ is the feed input signal, $L$ represents input information, $U$ represents internal information, $Y_1$ represents output of the previous unit as the input signal of the next unit, $Y$ is the output signal, indicating that the link strength $E$ represents the adjustment threshold, and $W$ is the neuron Weight. The output of each neuron has only two states, ignition or misfire. In general, the gray worth of a pixel pollute by interference has a large difference from the gray value of surrounding pixel points. Therefore, when a pixel contaminated by noise passes through the PCNN neural network, its output is different from the output of the surrounding pixel, so that it can be determined whether the point is a noise point. Specifically, when a certain neuron ignites and most of the neighboring neurons do not ignite, demonstrate that the relevant point has been contaminated by noise, its corresponding gray worth should be upper than it actually is; when a certain neuron The ignition of most neighboring neurons does not ignite, which also demonstrate that the relevant pixel is contaminated, and its relevant gray value is lower than the standard value, the pixel is not contaminated.

In [15] Gu Xiaodong Point out a new image denoising method use PCNN for binary image denoising. In [16] Liu et al., based on the feature image Pulse interference, the combination of time-sharing matrix and PCNN is used to obtain a split-new image denoising method use PCNN time-sharing matrix. Image noise contaminated by impulse noise can be effectively removed. In [17], Zou Wenjie et al. proposed an improved PCNN denoising method based on the previous problem that the convolutional neural network can only remove binary noise and can not remove the gray image. Ma Yide et al. summarized the characteristics of impulse noise, combined pulse-coupled neural network with mathematical morphology, and put forward an image denoising method use PCNN combined with gray morphology. This method uses the synchronization pulse of PCNN. A feature is issued to locate the location of the noise, followed by mathematical shape filtering for noise reduction. Different PCNN denoising algorithms are proposed for different noise models. In [18], Liu Yuanmin et al. proposed a new PCNN-based adaptive strong denoising method for effective removal of salt and pepper noise. The special feature of this method is the introduction of a noise transition mechanism, which will be included. The area of the noise is denoised so that the details of the image are better preserved. Due to the wide application of wavelet algorithm, in [19] Guo Yecai proposed a PCNN-based wavelet domain ultrasound medical image denoising method use wavelet denoising. This method firstly processes the wavelet coefficients and then uses PCNN. To automatically modify the wavelet coefficients. In [20], Liu Li et al. analyzed the characteristics of adaptive median filtering and PCNN, and combined them to form a PCNN-based adaptive median filtering denoising method.

2.3. Wavelet neural network
Wavelet neural network replaces the normal neuron nonlinear activation function with nonlinear wavelet base.

**Figure 3.** Wavelet neural network structure

$q(t)$ represents mother wavelet, $f(t)$ represents noise image, and $s(t)$ is the noiseless image. Assume that training data set is $\{x,y\}^m_{i=1}$. Among them $x \in R^a$ and $y \in R$ establish a network model as

$$
\begin{align*}
    u &= x' \times w(h) \\
    h &= q \left( \frac{u - b}{a} \right) \\
    y &= \sum_{i} c \times h
\end{align*}
$$

(1)
Where, \( u \) and \( h \) represents input and output \( i \) node of the hidden part, where network parameters are

\[
\theta = \{ w, b, a, c \} \quad \quad (2)
\]

The optimization objective function based on the model is

\[
\min J(\theta) = \frac{1}{N} \sum_{i=0}^{N} (y_i - \hat{y}_i)^2 + \lambda R(\theta) \quad \quad (3)
\]

\( \hat{y}_i \) represents the predicted output, and \( R(\theta) \) is a regular term, which is solved by gradient descent.

The primitives and the whole structure of the network are determined based on the wavelet analysis principle, which can avoid the blindness of structural design. Wavelet neural networks also have some shortcomings. In the case of multi-dimensional input, as the input dimension of the network increases, the sample trained by the network grows exponentially, and the network structure becomes more complicated, which makes the convergence speed greatly reduced. It is not possible to adaptively select the appropriate wavelet base based on actual conditions. In [21] Deng Chao et al. proposed a method to remove pulse interference using wavelet neural network for the problem of impulse noise denoising. This method combines wavelet neural network and median filtering algorithm, and first uses wavelet neural network to perform noise pixels. The recognition divides the pixel into a noise pixel and a non-noise pixel, and then assigns a corresponding scale coefficient to the noise pixel according to the domain value, and finally outputs the result by combining the median filter. Literature [22] Cai Nian applied the wavelet network to biomedical images, achieved better noise reduction effects, which improved the work efficiency of the staff. Tang Weiqiang et al. applied the denoising technique using wavelet neural network in the field of laser image, achieved good denoising effect, effectively retaining the details of the image.

3. Specific case analysis

Early non-local mean filtering method, by constructing the image block filtering learning process framework and the five-layer neural network model, using the gradient descent reverse conduction algorithm and the ReLU function, the mean-square logarithmic error loss function, the Adam optimization function used. Perform small batch processing model training to get better noise reduction effect on keras framework.

3.1. Non-local mean noise reduction based on deep learning

The specific denoising framework is as follows

![Neural Network Denoising Framework](image)

Select a noise-free image block \( y \) from the training set, and the corresponding noise image block is \( x \). The image block \( x \) is model input, noise-free image block \( y \) is model output. The weight of the model is updated by the reverse conduction algorithm, and iteratively The learning method learns the functions between image blocks into the model created in this paper. \( x \) is a noise picture, \( y \) is a noise-free picture block, and the process of noise image formation is as follows

\[
x = \rho(y) \quad \quad (4)
\]

\[
f = \min \sum (y - f(x))^2 \quad \quad (5)
\]

Equation (5) represents the minimizing output image \( y \), the noise image \( x \). Equations (4) and (5) show that image denoising is obtain \( f \) that approximates \( \rho^{-1} \) possible. Since the mapping between images is too complicated. Therefore, in the actual denoising process, the denoising image needs to be
split into fixed-size image blocks, and then the machine learning learns the mapping function between the image blocks. In the denoising process, all image blocks in the image are denoised by the mapping function $g$, and finally the denoised image blocks are aggregated to form a complete noise-free image. The machine learning process is as follows.

![Image block based image denoising machine learning process](image_url)

**Figure 5.** Image block based image denoising machine learning process

4. Conclusion

Several network models introduced in the paper have achieved good results in denoising images, but there are also problems such as parameter setting and experimental data set size in the model. There is no fixed standard or basis for the setting of parameters in the model, and most of them are experimentally used to obtain the most suitable parameters. Further research is needed on this problem. The noise of some images is mixed noise. At present, most denoising methods can only denoise for a single noise. Therefore, using deep learning technology to remove Combined noise in the image is what we continue to study.

Acknowledgments

This work was supported by the Information+ Discipline Construction Project (5111823414) and the Science Research Level Improvement Project (5211823406) of Beijing Information Science & Technology University.

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