Image Filter Processing Algorithm Analysis and Comparison

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Abstract: In the process of capturing images by the camera, various noises will be generated due to the interference of the external environment or the interference of the internal environment. The noise must be filtered to ensure the accuracy of the size measurement. This article takes Gaussian noise and salt and pepper noise as examples. Experimental simulation analysis of image filtering by different filtering methods. Then combined with the image quality evaluation index to analyze the optimal image filtering processing method, finally it is concluded that the most suitable methods for Gaussian noise and salt and pepper noise filtering are adaptive Gaussian filtering and median filtering.

1. Introduction

In the 1950s, people began to propose digital image processing technology. From the aerospace field to medical and health, military science, agriculture, industry and other fields, digital image processing technology has developed rapidly. Image preprocessing occupies a very important position in digital images.

In digital images, many spots and similar interference image signals often appear on the image surface. Such interference signals are usually called noise. There are many reasons for these noises, which are mainly divided into two major reasons. The first is the appearance of noise from external factors in the process of mapping natural images to film or computer through various devices. For example, the current natural environment such as weather and other factors or the unstable placement of equipment during the shooting process can cause noise. The second is internal production. In the process of converting natural images into digital images, different conversion processes such as scanning, sampling, quantization, etc. must be carried out, and every step of the operation here will produce noise. The existence of noise is random, unpredictable and inevitable.

The cause of noise and the way of expression is different, so the classification is different. According to the different reasons, the classification is carried out according to the relationship between noise and signal. In order to introduce noise as a mathematical model, noise is usually divided into the following two categories: salt and pepper noise and Gaussian noise. Since the presence of noise will affect image quality, in order to be effective and reliable in subsequent image processing and analysis, noise must be filtered. Common filtering methods include median filtering, mean filtering, and Gaussian filtering.

2. Common image filtering methods

2.1 Median filter
Median filtering is a non-linear image filtering processing algorithm, which replaces the gray value of
a pixel with the median value of the gray value in the neighborhood of the pixel, so that the surrounding pixel values are close to the true value to eliminate isolated noise points. To achieve the purpose of smoothing the image [2].

Specific implementation method: Choose a 3*3 template as the two-dimensional smoothing template, as shown in Figure 1, overlap the center pixel 5 of the template with the 20 pixels in the rectangular box of Figure 2, and the pixel array in the template area is \{12, 16, 20, 23, 116, 11, 17, 27, 25\}, the array is processed in ascending order (or descending order) to get \{11, 12, 16, 17, 20, 23, 25, 27, 116\}, Replace 116 with the intermediate value of 20, and the final processing result is \{12, 16, 20, 23, 20, 11, 17, 27, 25\}. The isolated points in the neighborhood are removed, making the image smooth, reaching for the purpose of median filtering.

![3*3 smooth template](image1.png) ![Smoothing filter](image2.png)

2.2 Mean filtering
Mean filtering is a typical linear filtering algorithm. It refers to giving a template to the target pixel on the image. The template includes neighboring pixels around it, and then the average value of all pixels in the template is used to replace the original pixel value. The main application of the mean filter is to remove irrelevant details in the image, where "irrelevant" refers to a pixel area that is smaller than the size of the filter template. As shown in formula (1), \( f(x, y) \) is an image containing noise, and \( g(x, y) \) is an image after averaging filtering.

\[
g(x, y) = \frac{1}{n} \sum_{(x,y) \in m} f(x, y) \tag{1}
\]

Among them, \( n \) represents the number of pixels contained in the pixel point set \( m; m \) represents the point set of the pixel point and its neighboring pixels;

The commonly used mean filter templates are:

\[
\frac{1}{n} = \frac{1}{9} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}
\]

2.3 Gaussian filtering
Gaussian filtering is a linear smoothing filter, which is a process of weighted average of the entire image, that is, the value of each pixel is obtained by weighted average of itself and other pixel values in the neighborhood. The essence of filtering is Gaussian Convolution process of normal distribution and image [3]. The mathematical model of the Gaussian filter is a two-dimensional Gaussian filter function, as shown in formula (2):

\[
g(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{2}
\]

Among them, \( g(x, y) \) is the gray value of the selected pixel \((x, y)\); \((x, y)\) is the pixel coordinate of the two-dimensional plane; \( x, y \) is the distance between the pixel point \((x, y)\) and the center point; \( \sigma \) is the
standard deviation of Gaussian filtering, which represents the degree of dispersion of data. The commonly used 3x3 templates for Gaussian filtering are:

\[
\begin{bmatrix}
    1 & 2 & 1 \\
    2 & 4 & 2 \\
    1 & 2 & 1 \\
\end{bmatrix}
\]

If the size of the window template is \((2k+1) \times (2k+1)\), discretize \(g(x, y)\), then the element value at the position \((i, j)\) in the Gaussian kernel is the weight coefficient, as shown in formula (3):

\[
H(i, j) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(i-k)^2+(j-k)^2}{2\sigma^2}}
\]  

(3)

The Gaussian filtering algorithm can effectively remove the noise in the image, but while removing the noise, the detail information in the image will be lost, resulting in insufficient image clarity and serious image distortion [4].

2.4 Improved Gaussian filtering algorithm

As the Gaussian filtering algorithm has the above shortcomings, in order to improve the detection accuracy, it needs to be improved. Since the standard deviation \(\sigma\) plays a vital role in the smoothing effect of the image, this article improves the selection of \(\sigma\). Through observation and analysis, it is found that the variance of the pixel value has a positive relationship with the degree of dispersion of pixels in a certain area of the image. The greater the variance of the pixel value, the greater the degree of dispersion of the pixel; otherwise, the variance of the corresponding pixel value is relatively small [5]. In view of the proportional relationship between the weight of the Gaussian kernel coefficient and the variance, the Gaussian kernel standard deviation is obtained according to the variance. First, calculate the variance in a certain area, as shown in formula (4):

\[
I(i, j) = \frac{\sum_{(x, y) \in F(i, j)} (x - \bar{x})^2}{|F(i, j)|}
\]

(4)

Among them, \(F(i, j)\) represents the neighborhood range near the center point \((i, j)\). The larger the variance \(I(i, j)\), the greater the degree of dispersion of the pixel matrix in the area, and the need to reduce \(\sigma\). Conversely, it is necessary to increase \(\sigma\).

According to this characteristic, the variance \(I(i, j)\) is compared with the two-dimensional Gaussian filter function \(H(i, j)\) to obtain the function \(Q(i, j)\), as shown in formula (5):

\[
Q(i, j) = \frac{I(i, j)}{H(i, j)}
\]

(5)

In the formula, \((i, j)\) represents the coordinates of the center pixel in the convolution window. Since \(I(i, j)\) is a constant, \(H(i, j)\) is a function of the Gaussian kernel radius \(k\) and the standard deviation \(\sigma\), as shown in formula (6) :

\[
\sigma = \frac{1}{Q} e^{\sqrt{(i-k-1) + (j-k-1)}}
\]

(6)

It can be seen that the value of \(\sigma\) changes as the variance \(Q\) changes, forming a new adaptive Gaussian filter.

3. Experimental simulation and analysis

3.1 Grayscale of image

Generally speaking, the images collected by the camera are all color RGB images, where the color of each pixel is determined by the three components of R, G, and B, representing the colors of the three channels of red, green, and blue. The value range is 0–255. The grayscale processing of the image is to convert the color RGB image into a grayscale image. The grayscale image removes the color information and only retains its brightness information. Therefore, the amount of grayscale image information will be significantly reduced, making the subsequent image processing easier and faster. In this article, the
most commonly used gray-scale processing method, namely the weighted average method, is based on the importance and other indicators, and the three components are weighted and averaged with different weights. Because the human eye has the highest sensitivity to green, it is more sensitive to blue. The sensitivity is the lowest, therefore, the three components of RGB are weighted and averaged according to formula (7), and then the gray image is obtained [6].

\[
Gray(i,j) = 0.299R(i,j) + 0.578G(i,j) + 0.114B(i,j)
\]  

(7)

The simulation results of sheet metal parts are shown in Figure 3.

![Original image](a) Original image ![Grayscale](b) Grayscale

Figure 3 Simulation effect

3.2 Image filtering

In order to better see the filtering effect, the common salt and pepper noise and Gaussian noise are added to the gray-scaled sheet metal parts image, and then the median filter, mean filter, Gaussian filter and adaptive Gaussian filter are processed respectively. Compare and analyze the processing effect.

The effect of adding salt and pepper and Gaussian noise to the grayscale image, and the results are shown in Figure 4:

![Add Gaussian noise](a) Add Gaussian noise ![Add salt and pepper noise](b) Add salt and pepper noise ![Grayscale](c) Grayscale

Figure 4 Effect of adding noise

Four filtering algorithms are applied to the image with salt and pepper noise, and the results are shown in Figure 5:

![Median filter](a) Median filter ![Mean filtering](b) Mean filtering ![Gaussian filtering](c) Gaussian filtering ![Adaptive Gaussian filtering](d) Adaptive Gaussian filtering

Figure 5 The effect of salt and pepper noise treatment

Four filtering algorithms are performed on the image with Gaussian noise, and the results are shown in Figure 6:

![Median filter](a) Median filter ![Mean filtering](b) Mean filtering ![Gaussian filtering](c) Gaussian filtering ![Adaptive Gaussian filtering](d) Adaptive Gaussian filtering

Figure 6 Gaussian noise processing effect
Through the comparison and analysis of simulation images, it can be intuitively found that the median filtering effect is the best for removing salt and pepper noise, and the obtained image is the cleanest and clearest. The removal effect of mean filtering and Gaussian filtering and adaptive Gaussian filtering is relatively close, and the comparison is not very clear. For Gaussian noise, the four filtering results are relatively similar, and it is not possible to directly observe the quality of the evaluation with the naked eye. In view of this, the evaluation index is introduced to evaluate the image quality, and three indexes of peak signal-to-noise ratio $\text{PSNR}$, average absolute error $\text{MAE}$ and structural similarity $\text{SSIM}$ are used to objectively evaluate the difference in processing effect of filtering algorithms.

The peak signal-to-noise ratio ($\text{PSNR}$) and mean absolute error ($\text{MAE}$) can be used to reflect the difference between the original image and the processed image. The higher the peak signal-to-noise ratio, the better. If it is higher than 40 dB, the image filtering effect is excellent. The processed image is close to the original image. A value between 30 and 40 dB means that the image filtering effect is better, and the processed image quality is better. There is some image quality loss but it is not obvious. If it is between 20 and 30 dB, it means the image filtering effect is poor and the image distortion is obvious. If it is lower than 20 dB, it means the image quality is extremely poor, indicating that the algorithm effect is unacceptable.

As the name implies, the mean absolute error represents the average value of the absolute error between the images before and after processing. The smaller the error, the better the processing effect.

Structural similarity $\text{SSIM}$ is a measure of the similarity between two images, especially reflecting the similarity of image details and contours, etc. Its value ranges from 0 to 1. The larger the $\text{SSIM}$ value is, the less distortion the generated image will be compared with the real image [7].

Therefore, we calculated the image quality evaluation index peak signal-to-noise ratio $\text{PSNR}$, mean absolute error $\text{MAE}$ and structural similarity $\text{SSIM}$ for the above-mentioned filtered simulation result image. The results are shown in Table 1:

| Evaluation index | $\text{PSNR}$ | $\text{MAE}$ | $\text{SSIM}$ |
|------------------|---------------|--------------|--------------|
| Noise type       | Salt and pepper noise | 80.8134 | 76.4343 | 0.0023 | 0.0831 | 0.9999 | 0.9994 |
| Mean filtering   | Salt and pepper noise | 69.9700 | 73.6269 | 0.0480 | 0.0993 | 0.9997 | 0.9989 |
| Gaussian filtering | Salt and pepper noise | 70.4722 | 76.4557 | 0.0454 | 0.0543 | 0.9997 | 0.9998 |
| Adaptive Gaussian filter | Salt and pepper noise | 67.5135 | 76.5652 | 0.0496 | 0.0333 | 0.9991 | 0.9999 |

From Table 3-1, in the evaluation index for filtering salt and pepper noise by median filter, the peak signal-to-noise ratio is 80.8134 dB, which is greater than 40 dB, the average absolute error is only 0.0023, and the structural similarity value is 0.9999, which is very close to 1. It shows that the median filter has a very good filtering effect on salt and pepper noise. The filtered image is very close to the original image. The other three filters have similar evaluation indexes for salt and pepper noise, and their removal efficiency is not as good as the median filter. For the filtering of Gaussian noise, the peak signal-to-noise ratio of adaptive Gaussian filtering is 76.5652, which is greater than 40 dB, the average absolute error is only 0.0333, and the value of structural similarity is 0.9999, indicating that adaptive Gaussian filtering has the best filtering effect on Gaussian noise. Therefore, considering the filtering effect of the two types of noise and the complexity of the algorithm, the median filter is used to filter the salt and pepper noise and the adaptive Gaussian filter is used to filter the image.

4. Conclusion
This paper selects two common noises in daily life, namely salt and pepper noise and Gaussian noise,
uses different filtering methods to perform experimental simulations on these two noises respectively, and introduces the image evaluation index peak signal-to-noise ratio, mean absolute error, and structural similarity, analyse and compare the filtering results. From the experimental results, it can be seen that for different noises, the principles and methods of filtering noise removal are also quite different. For Gaussian noise, adaptive Gaussian filtering has the best effect, and for salt and pepper noise, the median filter processing effect is the best.

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References
[1] Ma, L. Yang, W.F. (2019) Comparison of various denoising methods in digital image processing[J]. Journal of Jilin Teachers College of Engineering and Technology,35(09):92-94.
[2] Wang, L. (2019) Research on On-site Detection of Grinding Wheel Shape Tolerance Based on Machine Vision[D]. Chongqing University of Technology.
[3] Zhou, W.X. (2019) Research on Recognition and Detection Technology of Workpieces with Holes Based on Machine Vision[D]. Hefei University of Technology.
[4] Li, J.F. (2020) Lossless denoising technology of ship wake image based on improved Gaussian filtering algorithm[J]. Ship Science and Technology,42(18):37-39.
[5] Li, J. Ding, X.Q. Chen, G. Sui, Y. Jiang, N. (2019) Leaf image denoising method based on improved Gaussian filtering algorithm[J]. Journal of Southern Agricultural Sciences,50(06):1385-1391.
[6] Yang, W.H. (2020) Research and System Development of Part Geometric Measurement Technology Based on Machine Vision[D]. Xi'an University of Technology.
[7] Xiong, P.W. Tong, X.B. Song, A.G. Liu, X.P. (2020) Robot cross-modal generative confrontation network based on variational Bayesian Gaussian mixture noise model[J]. Science in China: Information Science:1-18.