An adaptive median filtering of visual product image based on gradient direction information

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Abstract: In order to overcome the problems of long filtering process, low signal-to-noise ratio of output results and low integrity of image information in traditional image median filtering methods, a new research method of visual product image adaptive median filtering based on gradient direction information is proposed in this paper. Based on the digital representation of the visual product image, the gradient direction information method is used to extract the noise information in the visual product image, so as to improve the quality of image filtering. Finally, the adaptive median filtering of visual product image is completed by processing the median and extreme values of visual product image. The simulation results show that the filtering process of this method takes 0.25–0.45 min, the signal-to-noise ratio can reach 85 dB, and the integrity of image information varies from 97.5% to 98.2%, which proves that it effectively realises the design expectation.

Keywords: gradient direction information; visual product image; adaptive median filter; noise extraction.

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1 Introduction

In the process of image generation, acquisition and transmission, it is difficult to avoid the formation of noise information (Liu et al., 2020). Especially for visual products, the quality of image information directly affects their sales or reliability. The reason of these noises in the visual product information image is not only the image equipment itself, but also the influence of environmental factors in the image generation process. Noise information seriously affects the image quality (Zhao and Yang, 2020). Therefore, in order to reduce the adverse effect of noise information on image interpretation and optimise the ratio of information to noise in the image, the image must be filtered. Among them, adaptive median filter is a more effective processing method (Wang et al., 2019a).

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In view of the above background, Gou (2019) designed an image median filter processing method based on quantum derivation. This method makes full use of the principle of quantum derivation and presents the normalised image in the form of quantum superposition state with the help of quantum information theory. After the disaster, based on the analysis of the principle of quantum Hadamard transform, set the median filter window and construct the image median filter algorithm. However, in practical application, it is found that the filtering process is time-consuming. Wang et al. (2020) designed a timing optimised median filtering method based on FPGA. Firstly, the tertiary input comparator module is changed into a secondary input comparator cascade module, which can process the data in multiple beats, so as to effectively reduce the timing lag in the filtering process and improve the clock frequency of the algorithm. On this basis, the parallel filtering process of extreme value comparator module is optimised, and the median filtering process is designed by field programmable gate array. However, in practical application, it is found that this method has the problem of low signal-to-noise ratio of output results. Wang et al. (2019b) designed an iterative adaptive median filtering method for eliminating salt and pepper noise. This method fully follows the principle of cyclic iterative processing. On the basis of the existing decision-based filtering methods, reasonably adjust the size of the filtering window, accurately calculate the median value of non-salt and pepper pixels in the filtering window, and then replace the noise pixels with the median calculation results, then the salt and pepper noise in the image is eliminated according to the noise density. However, in practical application, it is found that this method has the problem of low image information integrity.

Aiming at the problems of long filtering time and low integrity of image information in traditional median filtering methods, an adaptive median filtering method for visual product image based on gradient direction information is proposed. The overall research technical route of this method is as follows:

1 Analyse the nature of visual product image, and digitally represent the visual product image.

2 The gradient direction information method is used to extract the noise information in the visual product image, and then the adaptive median filter is completed by processing the median and extreme values of the visual product image.

3 The simulation results show that the filtering process of this method takes 0.25–0.45 min, the maximum signal-to-noise ratio can reach 85 dB, and the image information integrity changes between 97.5–98.2%, which proves its effectiveness.

2 Adaptive median filtering of visual product image based on gradient direction information

2.1 Digital representation of product image

Generally speaking, due to different ways of expression, images can be divided into continuous images and discrete images. Among them, the change of pixel position in different directions and the change of grey value at different pixels of continuous image are continuous, and the grey value at each pixel has infinite value (Xu and Liu, 2020; Shuai et al., 2019; Liu et al., 2019; Zhu and Wu, 2019).

If the visual product image to be processed is a still image, that is, the image content does not change with time, the mathematical expression of the image is:

$$I = F(x, y, z) \tag{1}$$

where (x, y, z) represents the spatial coordinates of image pixels.

At present, the information that can be processed by computer must be digital signal, and the visual product image to be processed is continuous analogue signal (Chen et al., 2020a). Therefore, the first step in the processing of the visual product image is to convert the information to be presented into digital form, that is, to discretise the continuously changing pixels in the image. The value space of various information related to image pixels is discretised into finite quantisation levels, and the image information is expressed in digital form.

If the visual product image to be processed is sampled in an equally spaced format, a dot matrix distributed in rows/columns is obtained after sampling (Zhao and Yang, 2020). The number and interval of sampling points are very important to the sampling results, which will affect the distortion of the image to a great extent. Taking the image signal $I(t)$ as an example, if the maximum frequency of the signal is p, there is:

$$I(t) = \sum_{i=-\infty}^{\infty} I(it) s(t - iT) \tag{2}$$

where T represents the sampling period, $i = \cdots, -2, -1, 0, 1, 2, \cdots$.

If the image is sampled at an interval of $T \leq \frac{1}{2p}$, $I(it)$ can be completely restored to zero according to the sampling results.

After sampling, the amplitude of the image signal needs to be discretised and layered, so as to form an image data structure convenient for computer processing (Shi and Tong, 2020). In this process, firstly, a visual product image is divided into several small squares, and the grey level of each small square can be expressed by integer grey level. Pixel is the smallest unit of this image, and its attributes include pixel position and grey value. The position of the pixel in the image is determined by the row and column where the pixel is located, that is, it is represented by (x, y, z), and the matrix element is the pixel value on the corresponding pixel.

To sum up, taking the numerical matrix of image $I_{M \times N}(x, y, z)$ as an example, $M \times N$ indicates that the pixels of the visual product image in the space have rows, M and N columns. Then the numerical matrix of image $I_{M \times N}(x, y, z)$ is expressed as follows:

$$I_{M \times N}(x, y, z) = \begin{bmatrix} I(0,0) & I(0,1) & \cdots & I(0, N-1) \\ I(1,0) & I(1,1) & \cdots & I(1, N-1) \\ \vdots & \vdots & \ddots & \vdots \\ I(M-1,0) & I(M-1,1) & \cdots & I(M-1, N-1) \end{bmatrix} \tag{3}$$

Using the above process, the digital representation of visual product image is completed. Because the composition of images is different, but their common point is that they must ensure the high quality of images. Therefore, in the process of digital representation of visual product images, it is necessary to fully consider how to maintain the visual display quality of images at a high level.

2.2 Noise information extraction based on gradient direction information

If we want to filter the noisy visual product image, we need to take a large amount of data as the basis. Therefore, before filtering, this paper first analyses the noise information of the visual product image, then integrates the data in the image into a multi-dimensional structure through modelling, and then uses the gradient direction in the gradient direction information to segment the image to obtain the results of functional region and non functional region.

Under normal circumstances, the types of noise information in the image have many forms, which can be roughly divided into Gaussian noise, Rayleigh noise, salt and pepper noise, gamma noise and so on (Chen et al., 2020b).

Among the different types of noise information contained in visual product images, Gaussian noise and salt and pepper noise are more, and gamma noise accounts for a relatively small proportion. Therefore, Gaussian noise and salt and pepper noise are deeply analysed in this paper.

The Gaussian noise in the image of visual products is mainly due to the insensitive sensing process, too high-noise density and so on. In the following, Gaussian noise is reflected in the form of function, and the process is as follows:

$$G = \frac{exp\left(\frac{E+h}{\rho}\right)}{\sqrt{2\pi}} \tag{4}$$

where: h represents the grey value of the visual product image, E represents the expected value of Gaussian noise on the image grey in the visual product image, and ρ represents the power spectral density of the visual product image.

The main reason for salt and pepper noise in visual product images is that it will actively collect information in the environment in the process of image formation. Once the complexity of environmental information is high, complex environmental information is particularly easy to be transformed into salt and pepper noise. The following uses the form of function to reflect the salt and pepper noise, and the process is as follows:

$$J = \frac{2\exp\left(-\frac{(h-j)^2}{\rho}\right)}{k}(h-j) \tag{5}$$

where j represents the complexity factor in the visual product image generation environment and k represents the correlation between the visual product image data and the original data.

Based on the above analysis of the noise type of visual product image, the gradient direction information is used to accurately extract the noise information. The calculation results of image gradient direction are as follows:

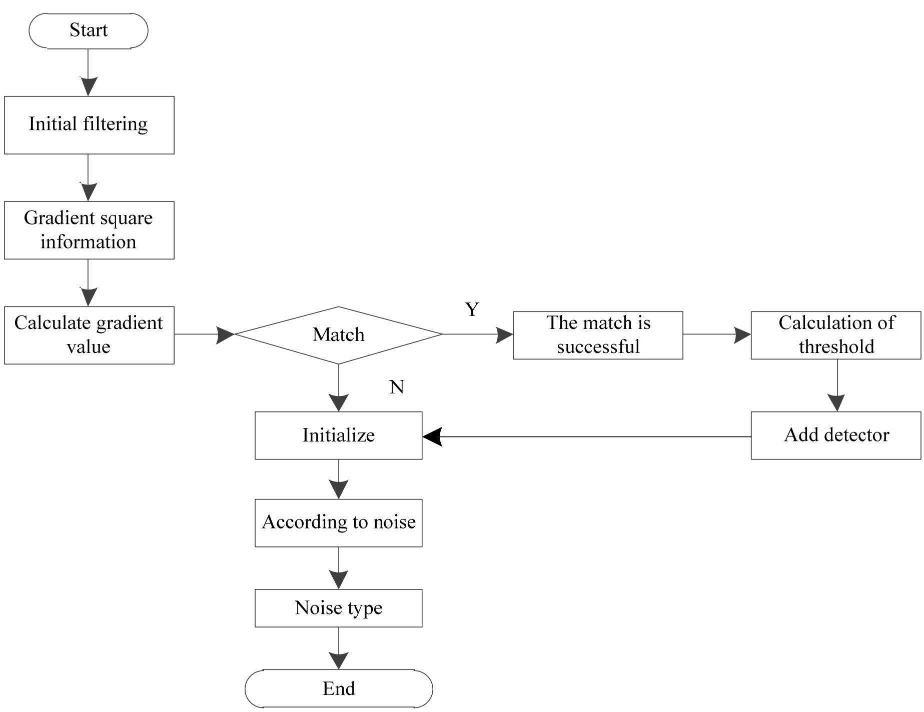
$$f = \frac{PQ}{G + J} \tag{6}$$

where f represents the calculation result of the gradient direction of the visual product image, and P and Q are the average noise waves of different types in the image, respectively.

Combined with the above pre-processing results, a noise extraction process based on gradient direction information is proposed in this paper. In this process, the dynamic detector is used to identify the initial noise category of the visual product image, so as to obtain the maximum value of non noise in the visual product image and complete the gradient direction detection, and then combined with all the binary noise data in the visual product image noise to judge the data points of the image noisy area, so as to realise the registration of noise types. If it is found that the binary parameters of noise can be copied or the noise changes during the registration process, the changed noise is discriminated according to the gradient direction information, so as to put forward all the noise information (Qu and Niu, 2018).

The noise information extraction process of visual product image is shown in Figure 1.

Figure 1 Noise information extraction flow chart of visual product image



2.3 Adaptive median filter processing

In order to avoid the influence of noise information on the image quality of visual products, this study implements adaptive median filtering in the UI interface environment.

The adaptive median filter will process the middle points in the neighbourhood of the visual product image and the points near the middle point, copy all the pixels according to the weight of each pixel, and arrange them according to the grey scale of the pixels. Suppose there is a discrete sequence, which is expressed as $a_1, a_2, ..., a_n$, and the corresponding non negative integer weights of the sequence are $\omega_1, \omega_2, ..., \omega_n$ in turn. On this basis, the weighted median filter is defined as follows:

$$C = Med\left\{a_1 \odot \omega_1, a_2 \odot \omega_2, ..., a_n \odot \omega_n\right\} \tag{7}$$

where C represents the filtered output and $\odot$ represents the copied visual product image data.

Assuming that the weighted window in the adaptive median filter processing is 3, the weighted filter can be copied twice in the central pixel and once in other pixels. The copied median of the new sequence is used as the output, and the results are as follows:

$$C_i = W_{eight-Med}\left\{a_{i-1}, a_i, a_{i+1}\right\} = Med\left\{a_{i-1}, a_{i-1}, a_i, a_i, a_i, a_i, a_{i+1}a_{i+1}\right\} \tag{8}$$

After 3 times of weighting, the value of which can be filtered according to 3×3, and set the initial window to $a_{i+1,j-1}, a_{i+1,j}, a_{i+1,j+1}$, then the weighted image can be expressed as:

$$\begin{aligned} C_{i+j} &= W_{eight-Med}\left\{a_{i-1,j-1}, a_{i-1,j}, a_{i-1,j+1}, a_{i,j-1}, a_{i,j}\right\} \\ &= Med\left\{a_{i-1,j-1}, a_{i-1,j}, a_{i-1,j}, a_{i-1,j+1}, a_{i,j-1}, a_{i,j}\right\} \end{aligned} \tag{9}$$

Considering the strong correlation between adjacent pixels of the image, the difference between noise grey value and adjacent pixel grey value is also strong. Therefore, the extreme value of pixel grey value needs to be further processed after weighting.

Select a $(2n+1)\times(2n+1)$ filter window in the image data and sort the pixels in the window. The pixels with the largest or smallest grey level in the window are determined as noise points and replace the existing grey value. The grey values in other signal points are not processed, which can be expressed as:

$$R_{i,j} \in \begin{cases} n, R_{i,j} = \min\left(W\left(R_{i,j}\right)\right), \max\left(W\left(R_{i,j}\right)\right) \\ s, \min\left(W\left(R_{i,j}\right)\right) < R_{i,j} < \max\left(W\left(R_{i,j}\right)\right) \end{cases} \tag{10}$$

In the formula, n represents the noise point in the visual product image, s represents the signal point, $\min\left(W\left(R_{i,j}\right)\right)$ represents the pixel window of the visual product image, $W\left(R_{i,j}\right)$ represents the minimum value of the point in the window and $\max\left(W\left(R_{i,j}\right)\right)$ represents the maximum value of point $W\left(R_{i,j}\right)$ in the pixel window.

To sum up, after processing the median and extreme values of the visual product image, the adaptive median filter processing is completed.

3 Experiment and result analysis

In order to verify the practical application performance of the above designed adaptive median filtering method for visual product image based on gradient direction information, the following experiments are designed to verify it.

3.1 Experimental environment design

The simulation verification experiment is carried out in the MATLAB simulation platform. The MATLAB GUI is simple, intuitive, easy to adjust and easy to modify the program to improve the efficiency of the simulation experiment. The experimental data comes from visual images in MySQL, and the size of the image data is 20 GB.

In order to improve the explicability and effectiveness of the experimental results, this method, image median filtering method based on quantum derivation and timing optimisation median filtering method based on FPGA are used for experimental comparison, and the experimental platform and environmental equipment are always consistent.

3.2 Experimental index design

The following experimental indexes are selected in this study:

1) *The filtering process is time-consuming*: The time-consuming of the filtering process can reflect the work efficiency of different processing methods. The less time-consuming the filtering process, the higher the efficiency of the image processing method; On the contrary, the more time-consuming the filtering process, the lower the efficiency of the image processing method.
2) *Output signal-to-noise ratio*: This index can directly reflect the effectiveness of different image processing methods, which is the ratio of useful information and noise in the processed image results. The higher the signal-to-noise ratio of the output results, the higher the effectiveness of the image processing method; On the contrary, the lower the signal-to-noise ratio of the output result, the lower the effectiveness of the image processing method.
3) *Image information integrity*: This index refers to the complete presentation of information in the image after filtering by different image processing methods, which can directly reflect the reliability of different image processing methods. The higher the integrity of image information, the more effective the image processing method can filter out the influence of noise on the image and more truly and comprehensively show the information of the image itself.

3.3 Experimental results and analysis

3.3.1 The filtering process of different methods is time-consuming

Firstly, the time consumption of filtering process of different image processing methods is counted, and the results are shown in Table 1.

Table 1 Time consuming statistical results of filtering process of different image processing methods (min)

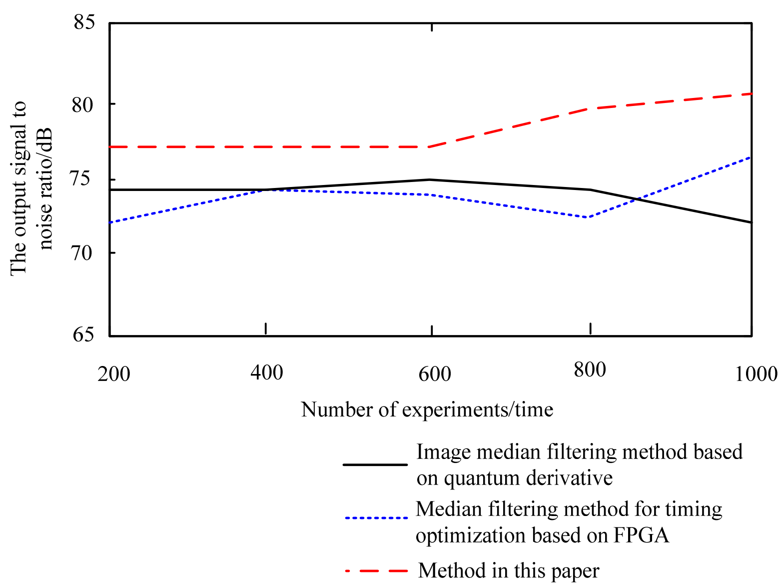
Number of experiments/time	*Image median filtering method based on quantum derivation*	*Timing optimisation median filtering method based on FPGA*	*Paper method*
200	0.73	0.81	0.34
400	0.95	0.72	0.25
600	0.74	0.65	0.45
800	0.72	0.91	0.43
1000	0.84	1.43	0.44

By comparing and observing the results in Table 1, it can be seen that after applying the image median filtering method based on quantum derivation, with the continuous increase of test times, the time-consuming of the filtering process fluctuates between 0.72 min and 0.95 min; After applying the timing optimised median filtering method based on FPGA, with the increasing number of tests, the filtering process time-consuming fluctuates between 0.65 min and 1.43 min; After the application of this method, with the continuous increase of test times, the time-consuming of the filtering process fluctuates between 0.25 min and 0.45 min. Through the above comparison, it can be seen that the filtering process of this method takes less time, indicating that this method has higher efficiency.

3.3.2 SNR test of output results of different methods

In order to verify the effectiveness of different image processing methods, take the signal-to-noise ratio of output results as the index to test the performance of different methods, and the results are shown in Figure 2.

Figure 2 Comparison of signal-to-noise ratio of output results of different image processing methods



By analysing the results shown in Figure 2, it can be seen that the signal-to-noise ratio of the output results of the method in this paper is stably maintained at 77 dB in the first 600 iterations, and then increases. The signal-to-noise ratio values are maintained above 77 dB, up to 85 dB, which is significantly higher than the two traditional methods. The output signal-to-noise ratio curve of image median filtering method based on quantum derivation and timing optimisation median filtering method based on FPGA is below the curve of this method, and the change is obvious. It can be explained that after the processing of this method, the ratio of useful information to noise in the image results is higher, which also shows that this method is more effective.

3.3.3 Image information integrity testing with different methods

Finally, taking the integrity of image information performance as the index, the application performance of this method, image median filtering method based on quantum derivation and timing optimisation median filtering method based on FPGA is compared and tested. The results are shown in Table 2.

Table 2 Statistical results of image information integrity of different image processing methods (%)

Number of experiments/time	*Image median filtering method based on quantum derivation*	*Timing optimisation median filtering method based on FPGA*	*Paper method*
200	82.5	85.8	97.7
400	82.7	84.7	97.6
600	82.3	86.5	97.5
800	82.5	86.2	98.2
1000	81.6	86.3	97.4

By comparing and observing the results in Table 2, it can be seen that after applying the image median filtering method based on quantum derivation, with the continuous increase of test times, the integrity of image information performance changes between 81.6% and 82.7%; After applying the timing optimised median filter method based on FPGA, with the increasing number of experiments, the integrity of image information varies from 84.7 to 86.5%; After the application of this method, with the increasing number of experiments, the integrity of image information varies from 97.5 to 98.2%. Through the above comparison, it can be seen that the image information performance integrity of this method is higher, which shows that this method can more effectively filter out the influence of noise on the image, so as to more truly and comprehensively display the information of the image itself.

4 Conclusion

Aiming at the problems of long filtering process, low signal-to-noise ratio of output results and integrity of image information in traditional image median filtering methods, an adaptive median filtering method for visual product image based on gradient direction information is designed in this study. Based on the digital representation of visual product image, the noise information in visual product image is extracted by gradient direction information, and then the adaptive median filter is completed by processing the median and extreme values of visual product image. The experimental results show that the filtering process of this method takes 0.25–0.45min, the signal-to-noise ratio can reach 85 dB, and the integrity of image information varies from 97.5 to 98.2%, indicating that it has high application advantages.

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