Analysis of Denoising Method and Study of Denoising Fusion Optimization Algorithms for Industrial Gear Image

Dan Liu[1, 2, a], Xiaogang Wang[1, 2] and Shuchuan Gan[1, 2]
[1]School of automation and information engineering, Sichuan university of science and engineering, Yibin, 643030, China
[2]Artificial intelligence key laboratory of Sichuan,Yibin, 643030, China

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Abstract: Aiming at the problem of noise filtering in the detection of industrial gear defects by machine vision technology, this paper makes some analysis and study for industrial gear image. For the analysis of denoising method, it uses the method of MATLAB numerical simulation to apply single noise (like Gauss noise, salt and pepper noise, multiplicative noise) to gear image, and uses median filter, mean filter, Gaussian smoothing filter and Wiener filter separately to filtering and compare the different filtering effects. For the study of denoising fusion optimization, a neighborhood mean method based on extremum median filter and a fusion filter method are proposed for the mixed noise. The simulation results show that the median filtering is the best for salt and pepper noise, the smooth filtering and Wiener filtering are better for Gauss noise and multiplicative noise, and the fusion filtering method with improved mean filtering is the best for gear images with mixed noise.

1 INTRODUCTION

As the basic element of industry, gear is the most basic and key component in manufacturing equipment industry. Its precision directly affects the working performance and service life of the machine, so the quality inspection technology of gear has become a focus of attention and research (Yang, Y.H. Yang, Y. and Yu C. B, 2018). In recent years, machine vision technology has been widely used in defect detecting of product and image recognition (César, D. Jónathan, H. and Pascual, V, 2017; Ma, Y. Jiang, Q. 2018), the technical scheme is mature, which improvs the quality and the flexibility of industrial production. Therefore, it can also be applied to the real-time monitoring of industrial gear (Wu, Q. Gu, J.N. and Zhang, P.L, 2017; Yin, H.M, 2017).

The defect detecting of gear based on image recognition mainly includes image preprocessing (filtering and enhancement) (Dong, C.Z. Ye, X.W. and Jin, T, 2017), edge inspection (Peng, H. Zhao, P.B, 2017), target extraction (Shan, Z.W, 2017), region segmentation and defect feature extraction (Cui, J.H. Zhao, W.X. and Wang, X.Z, 2009). Among them filter regards primary job, its importance is self-evident. For the detection of engine defects, Xiao Jing proposed wavelet transform can be applied to image denoising (Xiao, J. You, S.H, 2018), and the effect was greatly improved compared with the median filtering. For the needs of image processing, Bi Siwen proposed an image denoising algorithm based on double tree complex wavelet transform. Compared with other methods (Bi, S. Chen, W.H. and Shuai, T. et al, 2019), the PSNR of the denoised image was improved 0.2dB. In the sonar detection image of submarine pipeline, it is easy to be influenced by the external environment. On the basis of wavelet, Liu Xiaojuan et al. proposed an ultra-wavelet ridged wave transform with the function of maintaining linear features such as obvious edges (Zhang, X.J. Liu, Z. and Yang, X. et al, 2017). For the industrial gear, its image mainly includes the noise of itself, the electronic noise generated by the high-speed camera, and the quantization noise of the digital image. Among them, the noise of itself is mainly affected by the environment, such as light and air quality. The noise can be controlled and can be ignored due to the small error. Digital image noise is generated in the process of digital sampling of the original image and it is inevitable. For the electronic noise produced by high-speed camera, it cannot be ignored and is the most important factor affecting the gear image. Gear image noise can be divided into

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gaussian noise, salt-pepper noise and multiplicative noise. Because of that each noise has its own characteristics, so different filtering methods are required (Li, J. Deng, F. and Chen, J, 2018; Erkan, U. Gökrem, L. and Enginoğlu, S, 2018).

In order to get better image preprocessing effect, the MATLAB is used to simulate calculation (Li, X.M. Zhang, Q.W. and Ying, G.Z, 2012), the noises in gear images are filtered by various methods, and the best filtering method of each noise is obtained. Finally, the best filtering method to a mixture of gaussian noise and multiplicative noise of the gear image is obtained.

2 FILTERING ANALYSIS

Assuming that industrial gear images mainly includes gaussian noise, salt-pepper noise and multiplicative noise. Median filter, mean filter, gaussian smooth filter and two-dimensional adaptive wiener filter are proposed to filter the above noises respectively, and the optimal filtering method of each noise can be obtained.

2.1 Gaussian Noise

Gaussian noise in industrial gear images mainly comes from the electronic noise generated by high-speed cameras. Due to the extremely short exposure time and sufficient light in the real-time monitoring process of gears, the noise of high-speed cameras conforms to the characteristics of gaussian noise. Gaussian noise can be expressed by probability density function.

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp[-(x-u)^2 / 2\sigma^2] \qquad (1)$$

x is pixel value, u is the average of image gray value, σ^2 is the standard deviation of pixel value, is the variance of pixel value. In the Matlab program, the density of gaussian noise depends on the formula $G(u,\sigma^2)$. For each input pixel value, a normal gaussian sampling distribution formula can be used to obtain the output pixel value.

$$P = x + uMeans + \sigma^2 * G(d) \qquad (2)$$

d is a linear random number and $G(d)$ is the gaussian random value of the random number. The sequence of adding gaussian noise to the gear image is shown in Fig.1.

According to the process in Fig.1, gaussian noise is adding to the original gear image in Matlab, where the u is 0 and the σ^2 is 0.05. The results are shown in Fig.2, where Fig.2 (a) is the actual image of the industrial gear and Fig.2 (b) is the image after gaussian noise is applied.

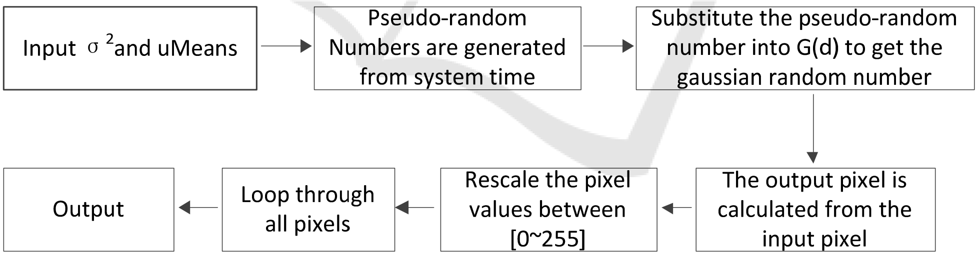

Figure 1. Sequence of adding gaussian noise.

Figure 2(a). Original gear image.

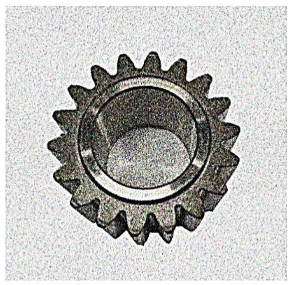

Figure 2(b). Adding gaussian noise.

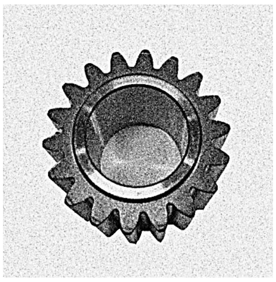

Figure 3(a). Median filtering.

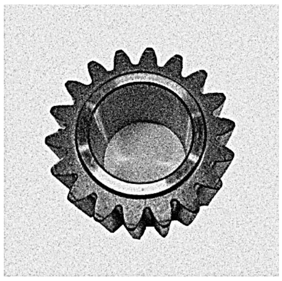

Figure 3(b). Mean filtering.

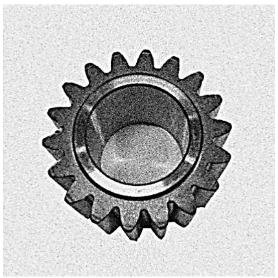

Figure 3(c). Gaussian smooth filtering.

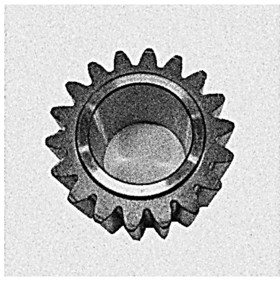

Figure 3(d). Wiener filtering

As shown in Figure 2(b), gaussian noise is a color noise. Median filter, mean filter, gaussian smooth filter and two-dimensional adaptive wiener filter are respectively performed on the gear images. The filtering result of each method is shown in Figure.3.

As shown in Fig.3, there is little difference in subjective evaluation of gaussian noise. From the perspective of objective evaluation, peak-signal-to-noise-ratio (PSNR) is proposed to carry out full reference evaluation in order to clarify the advantages and disadvantages of each filtering method. The PSNR values of each method are shown in Table 1.

Table 1. Evaluation index of image filtering with gaussian noise.

Methods	Noise image	Median filtering	Mean filtering	Gaussian smooth filtering	Wiener filtering
PSNR	21.71	31.39	32.114	32.987	34.46

It can be seen from Table 1 that PSNR value of gear image with noise is 21.715dB.The PSNR values after median, mean and gaussian smoothing filter are all around 32dB.The image quality after wiener filtering is obviously better than the other three methods. The PSNR values of images filtered by each method are: wiener filter>aussian smooth filter>mean filter>median filter, so the best method to filter gaussian noise is wiener filter.

2.2 Salt-pepper noise

The salt-pepper noise may be produced in the process of high-speed photography and digital image quantization. Salt-pepper noise is a random occurrence of white or black dots. The sequence of adding salt-pepper noise in the digital image is shown in Fig.4.

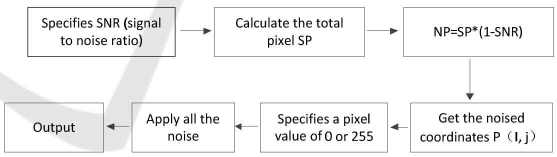

Figure 4. Sequence of adding salt-pepper noise in gears image.

In MATLAB, salt-pepper noise is adding to gear image, where SNR is 0.05. Fig.5 is the gear image with salt-pepper noise.

As shown in Fig.5, black or white dots appear in the image after noise is added, which conforms to the characteristics of salt-pepper noise. Median filter, mean filter, gaussian smooth filter and two-dimensional adaptive wiener filter were applied to the gear images. The filtering effect of each method is shown in Fig.6.

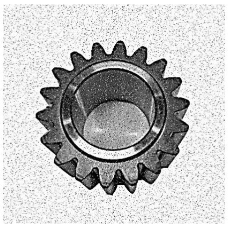

Figure 5. Adding salt-pepper noise.

Figure 6(a). Median filtering.

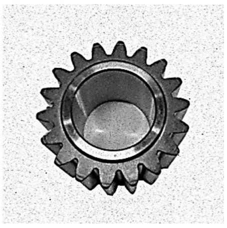

Figure 6(b). Mean filtering.

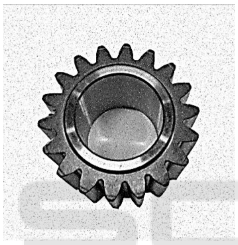

Figure 6(c). Gaussian smooth filtering.

Figure 6(d). Wiener filterin.

As shown in Fig.6, for the salt-pepper noise in gear image, the median filter has the best effect and basically eliminates the black and white noise. Among other filtering methods, the gaussian smooth filter is better than wiener filter and mean filter, but the filtering effect cannot be compared with the median filter. It is difficult to meet the requirements of image post processing. The reason is that in the process of median filtering, the value of each position in the filtering matrix is replaced by the median value, while the pixel value of the black point is 0 and the white point is 255, which belongs to the extreme value at both ends of the pixel. When the median value is taken, it can be basically eliminated, so that the filtering effect is better. Therefore, median filter should be used to preprocess industrial gear images with salt-pepper noise.

2.3 Multiplying Noise

Assuming that the pixel of the gear image is $f(i,j)$ and the pixel of the noise is $h(i,j)$, then both gaussian noise and salt-pepper noise belong to additive noise, the total pixel of the noise-containing image is $f(i,j)+h(i,j)$. If the total pixel value of the image is $f(i,j)*h(i,j)$, the noise is multiplicative noise. The multiplicative noise is closely related to signal of gear image. It varies with the intensity of the image signal. For the industrial gear image, in the process of image acquisition and image digitization, there will be some multiplicative noise due to the camera particle noise and other reasons. Fig.7 shows the superposition of multiplicative noise in the original image.

Figure 7. Adding multiplicative noise.

As shown in Fig.7, compared with gaussian noise and salt-pepper noise, multiplicative noise is more densely distributed and has a greater impact on the image. Median filtering, mean filtering, gaussian smoothing filtering, and two-dimensional adaptive wiener filtering were performed on the gear images. The filtering effect of each method is shown in Fig.8.

Figure 8(a). Median filtering.

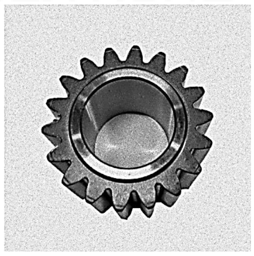

Figure 8(b). Mean filtering.

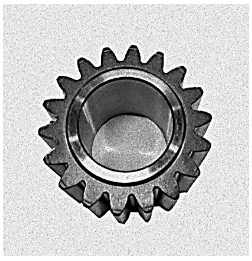

Figure 8(c). Gaussian smooth filtering.

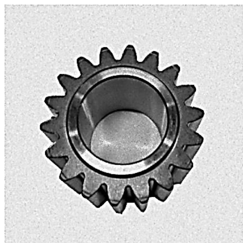

Figure 8(d). Wiener filtering.

Table 2. Evaluation index of image filtering with gaussian noise.

Methods	Noise image	Median filtering	Mean filtering	Gaussian smooth filtering	Wiener filtering
PSNR	24.32	32.835	33.008	33.752	36.813

Similar to gaussian noise, the above four filtering methods have little difference in subjective evaluation. In terms of objective evaluation, PSNR was used for full reference evaluation. The PSNR values of each method are shown in Table 2.

It can be seen from Table 2 that the PSNR values of images with multiplicative noise are all around 33dB after the median, mean and gaussian smoothing filtering. However, the wiener filtering is obviously better than the other three methods, and the peak-signal-to-noise-ratio after denoising is 36.813dB.

From what has been discussed above, wiener filter has the best effect among all kinds of noise filtering methods for gear image. It is suitable for gaussian noise and multiplicative noise. For salt-pepper noise, the median filter should be selected.

3 OPTIMIZED FILTERING

After median filtering, the quality of gear image with salt-pepper noise basically meets the requirements of image post-processing. Therefore, salt-pepper noise is no longer considered in the fusion noise, and gaussian noise and multiplicative noise are mainly superimposed. As shown in Fig.9, gaussian noise and multiplicative noise are superimposed on the original image.

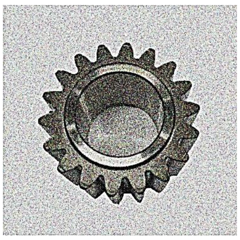

Figure 9. Gear image with gaussian noise and multiplicative noise.

3.1 Improved Mean Filtering

When filtering the gear image with fusion noise, the conventional filtering method is that all pixels are processed in the same way, but the filtering effect is poor. Based on the idea of extreme median filtering, the mean filtering can be improved and get the neighborhood mean method of domain value based on extreme median filtering. The basic idea is: select a pixel of the gear image, if the difference between its gray value and the average gray value of its neighborhood is greater than the given maximum value M(or less than the given minimum value N), then the average gray value of its neighborhood can be used to replace. The expression is as follows:

$$f'(x,y)=\begin{cases} f(x,y), & N \le \left| f(x,y)-\frac{1}{T}\sum_{m,n\in C} f(m,n) \right| \le M \\ \frac{1}{T}\sum_{m,n\in C} f(m,n)\ , & \text{else} \end{cases} \tag{3}$$

$f(x,y)$ is the gray value of the original image containing $S \times S$ pixels, and $f'(x,y)$ is the gray value of the processed image, x, y=0,1,2...S-1, C is the set of coordinates in the neighborhood of the (x,y), but it doesn't include the point (x,y), T is the total number of coordinate points in the set.

3.2 Composite Filtering

The gear images with fusion noise (gaussian noise and multiplicative noise) are filtered by the above four methods separately, and the filtering effect of each method is shown in Fig.10.

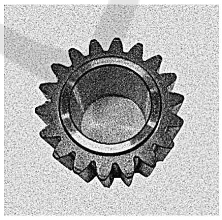

Figure 10(a). Median filtering.

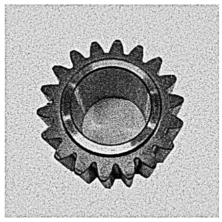

Figure 10(b). Mean filtering.

Figure 10(c). Gaussian smooth filtering.

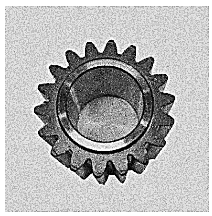

Figure 10(d). Wiener filtering.

Table 3. Filtering evaluation indicators for images with multiplicative noise.

Methods	Noise image	Median filtering	Mean filtering	Gaussian smooth filtering	Wiener filtering
PSNR	20.32	29.530	29.688	32.091	31.715

As shown in Fig.10, median filtering and mean filtering are poor. PSNR is still used for full reference evaluation in objective evaluation to characterize the effect of each filtering method. The PSNR values of each method are shown in Table 3.

It can be seen from Table 3 that after median filtering or mean filtering, the PSNR value of the noise image is about 29dB. However, the image quality after wiener filtering or gaussian smooth filtering is relatively good, and PSNR is 32dB, with better filtering effect.

In order to get the best filtering effect, multi-method superposition filtering is performed on the gear image on the basis of single filtering. As shown in figure 11, the original image is firstly processed by gaussian smooth filtering, then the secondary image is processed by wiener filtering, next the above improved mean filtering is performed, and finally the fourth image is processed by median filtering. Fig 12 shows the change of PSNR value of the original image after each filtering method.

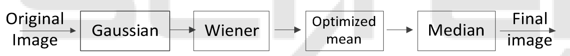

Figure 11. Sequence of fusion filtering.

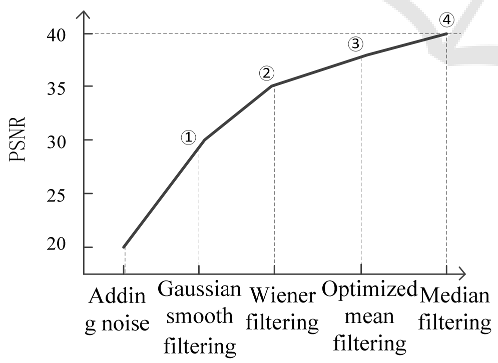

Figure 12. Multiple filtering of the fusion model.

As shown in Fig.12, after median filtering and mean filtering, the noise in the gear image basically disappears. And PSNR value of the image is basically equal to the original image, with good filtering effect. It can be seen from the slope of broken line, the gaussian filter has the highest slope and the best filtering effect. After gaussian filtering and wiener filtering, most of the image noise disappears, which is consistent with the conclusion in Table 3.

4 CONCLUSIONS

In order to describe all kinds of noise that may be encountered in the process of industrial gear image processing, single noise model and the fusion noise are analyzed respectively. The following conclusions are as follows: firstly, the median filter method should be used to remove the salt-pepper noise in the gear image, the result is obviously, which can basically remove all the noise. Secondly, for gaussian noise and multiplicative noise, the effect of each filtering method is little different, which can filter noise to some extent, the two-dimensional adaptive wiener filtering method is little better. For the fusion noise, when there are three kinds of noise in the image, the salt- pepper noise can be filtered out by the median filtering, gaussian smoothing and Wiener filtering are used to filter out the remaining Gaussian noise and multiplicative noise. Finally, on the basis of the existing filtering methods, a new filtering method is proposed for gear image noise, and the filtering effect is obvious.

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