An Image Denoising and Enhancement Algorithm for Inner and Outer Ring of Wavelet Bearings Based on Improved Threshold

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Abstract. In the bearing inner and outer ring surface defect detection, the traditional wavelet threshold algorithm is general effective for image processing of bearing images with insufficient illumination or uneven illumination. This paper proposes a method to improve the wavelet denoising enhancement of the threshold function. Firstly, the multilevel decomposition of bearing image is carried out by wavelet; Furthermore, adopted the improved algorithm and adaptive algorithm respectively to conduct the denoising enhancement for the first to third levels of wavelet coefficients; Finally, the wavelet coefficients and scaling coefficients are processed by wavelet inverse transform. Experiments showed that this algorithm can effectively denoise and enhance the contrast of images, processing images with good results, which is better than the traditional enhancement algorithms.

1. Introduction
The equipment of bearing is automatically checked by the inner and outer ring of the bearing, which can improve the accuracy and speed of detection. However, when the image is obtained, image distortion is caused by the imaging equipment, the light source and the surrounding environment, which makes the extraction of features difficult and hinder the trouble to be checked[1]. Digital images are inevitably affected by noise in the process of collection and transmission, resulting in certain difficulties in subsequent image processing such as segmentation and recognition. Therefore, the research of image denoising algorithms is an important content in digital image processing. [2]. Domestic and foreign scholars have proposed several classical image denoising algorithms. For example, non-local mean filtering [3], median filtering, low-pass filtering, other methods derived from Wiener filtering, etc. [4-5]

With the development of wavelet theory, wavelet has gradually become an effective tool to filter and select features. The common wavelet denoising is: threshold method, proportional shrinkage method, correlation method. As the threshold method is easy to calculate and relatively small in calculation, which is widely used. The early threshold method has the Visu Shrink method proposed by Donoho and Johnstone [6-7], the standpoint is: to compare the coefficients of the series and a certain threshold in the coefficients of each layer of wavelet decomposition, and then to deal with the coefficients of the coefficients larger than and less than the threshold, and reconstruct the wavelet coefficients. The choice of threshold function is crucial in this process [8-11]. The essence is to reduce the noise, the maximum to retain the true coefficient, and finally uses the wavelet inverse transforms to get the best estimate.
2. Bearing Image Two-Dimensional Wavelet Transform

Wavelet transform is a new multiscale signal analysis method and the multiresolution analysis of two-dimensional wavelet transform is the direct extension of one-dimensional case. If \( u(x) \) and \( v(x) \) represent the scale function and the wavelet function in one-dimensional case, the basis of two-dimensional wavelet transform is:

\[
u(x,y) = u(x)u(y)
\]

(2.1)

And three two-dimensional wavelets

\[
\begin{align*}
VH(x,y) &= v(x)u(y) \\
VV(x,y) &= u(x)v(y) \\
VD(x,y) &= v(x)v(y)
\end{align*}
\]

(2.2)

In the formula: \( u(x,y) \) is a separable scaling function; and \( VH(x,y), VV(x,y), VD(x,y) \) are three direction-sensitive wavelet functions.

When decomposed as \( j \) layer:

\[
\begin{align*}
A_j f(x,y) &= \{ f(x,y), u(x,y) \} \\
D_j^H f(x,y) &= \{ f(x,y), V_j^H(x,y) \} \\
D_j^V f(x,y) &= \{ f(x,y), V_j^V(x,y) \} \\
D_j^D f(x,y) &= \{ f(x,y), V_j^D(x,y) \}
\end{align*}
\]

(2.3)

3. Wavelet Threshold Denoising

3.1. Threshold Estimation

The Good threshold selection directly related to the effect of denoising in Wavelet denoising, threshold selection should be greater than the maximum noise, the maximum of the noise is lower than generally, so the selection threshold is:

\[
T = \sigma \sqrt{2 \log MN}
\]

In the formula: \( \sigma \) is the standard deviation of the noise image, and \( M \) and \( N \) are the size of two-dimensional image. In practice, \( \sigma \) is unknown and is usually estimated for \( \sigma \), the wavelet coefficients estimate for \( \sigma \):

\[
\sigma = \frac{\text{median}_{\text{chd}}}{0.6475}
\]

In the formula: \( \text{median}_{\text{chd}} \) represents the median of the first level wavelet coefficients.

Of course, the magnitude of the wavelet coefficients during noise processing decreases as the decomposition scale increases, the threshold \( T \) is not the most suitable and needs to be improved so that the threshold varies with the decomposition level.

\[
\lambda = \frac{T}{\log(j+1)}
\]

In the formula: \( j \) is the number of wavelet decomposition layers; \( \lambda \) is the threshold of \( j \) on the scale.

3.2. The Selection of Threshold Function for the First Stage Wavelet Coefficients

The threshold function is a method of processing the wavelet coefficients. The hard threshold function and the soft threshold function are commonly used functions for wavelet threshold denoising.
3.2.1. **Hard Threshold Function**

\[
W_{out} = \begin{cases} 
W_{in}, & |W_{in}| \geq \lambda \\
0, & |W_{in}| \leq \lambda 
\end{cases}
\]

Wout and Win are the wavelet coefficients before and after transformation. This method is to zero the wavelet coefficients the threshold in the image, and the wavelet coefficients above the threshold remain unchanged. The function preserves the features of the image larger than the threshold well, but due to the discontinuity of the shrinkage function, some artificial "noise point" are generated in the inverse transformed image to distort the reconstructed image.

3.2.2. **Soft Threshold Functions**

The method is to shrink the wavelet coefficients by a certain amount to zero. After the soft threshold treatment, the wavelet coefficient continuity is good, easy to handle, but certain shrinkage of the wavelet coefficients greater than the threshold, which can cause the image to lose high frequency information of usefully. Therefore, this paper has made some improvements on the basis of soft threshold.

3.2.3. **Improved Threshold Function**

\[
W_{out} = \begin{cases} 
W_{in} - t \lambda \sin \left( \frac{\pi}{2} \frac{|W_{in}|}{W_{in}} \right), & W_{in} \geq \lambda \\
0, & |W_{in}| \leq \lambda \\
W_{in} + t \lambda \sin \left( \frac{\pi}{2} \frac{|W_{in}|^2}{W_{in}} \right), & W_{in} \leq -\lambda 
\end{cases}
\]

By improving the threshold function effectively, the wavelet coefficients of the absolute value greater than the threshold value in the soft threshold method has a fixed deviation before and after treatment. Moreover, the lack of constant attenuation can further reduce the loss of high information which is frequent and improve the accuracy of reconstructed image. In the upper formula, the degree of attenuation is measured in Win. The attenuation decreases as the absolute value of the larger wavelet coefficient increases, reducing the attenuation and increasing the signal-to-noise ratio of the signal. Factor \(n\) can adjust the variation of this dynamic threshold and select \(n=1\). The factor \(t\) determines the signal-to-noise ratio of the image after wavelet processing, signal-to-noise ratio becomes smaller as \(t\) becomes larger. Otherwise, the image will be distorted with the decrease of the signal-to-noise ratio. As we all know, there is a golden point in mathematics - 0.618, known as the "magical" golden section. Therefore, Considering this statement in mathematics and engineering, taking \(t = 0.168\), which is a comprehensive hard threshold and soft threshold denoising method, through a large number of simulation experiments and found that this denoising method can get better Denoise effect, and easy to handle[12].

3.3. **Second And Third Wavelet Coefficient Processing Threshold Function Selection Adaptive Enhancement Algorithm**

In order to improve the visual effect of local image and the other region were not modified, anew adaptive algorithm was proposed, which based on Local Mean and Local Standard Deviation
Where $\lambda_1$ and $\lambda_2$ are threshold thresholds ($\lambda_1 < \lambda_2$), G is gain, Win and Wout are the wavelet coefficients before and after the transformation. In the experiment, G is related to the noise index, and the G’s value is relatively large when the noise is small, on the contrary, the G’s value is smaller. In the experiment, $\lambda_1$ and $\lambda_2$ were selected by using human-computer interaction.

4. Experiment
Select defective bearing images in the experiment, for this type of bearing image, adopted the standard deviation, signal-to-noise ratio, and contrast enhancement index as the criterion.

The mean square error is the mean square error of the image gray value. The contrast improvement index is defined as:

$$CII = \frac{C_1}{C_0}$$

Among them, $C_0$ is the contrast of the original image, $C_1$ is the contrast of the enhanced image, the contrast is defined as: $C = (f_{\text{max}} - f_{\text{min}}) / (f_{\text{max}} + f_{\text{min}})$, $f_{\text{max}}$ is the maximum value of the image gray, $f_{\text{min}}$ is the minimum value of the image gray. The average value of a local enhancement is resistance to noise performance compared with SNR [13].

$$MSE = \frac{1}{n} \sum_n \left( x_{ij} - x'_{ij} \right)^2$$

Image means square error (MSE) is defined as:

$$MSE = \frac{1}{n} \sum_n \left( x_{ij} - y_{ij} \right)^2$$

Where, i, j represents the position of each points in the image, $x_{ij}^2$ represents the original image; $x_{ij}'^2$ represents the image after the enhanced algorithm is processed, $y_{ij}$ means the image after the noise, $y_{ij}'$ represents the image after the noise is processed by the enhanced algorithm. For the same noisy image, the SNR of the processed image is bigger and the contrast is bigger, and the smaller the mean square error MSE is, the better the noise reduction effect.
Selected haar wavelet in the experiment and the image was decomposed at level 3. Since the noise is mainly concentrated in the first level wavelet, the modified threshold algorithm is used to process the wavelet coefficients, the $t = 0.618$; $N = 1$; for the wavelet coefficients of the second and third levels, the noise at these two levels is relatively small, and the selection of this text is from the adaptive enhancement algorithm $G = 8$; in the second-order wavelet algorithm, $\lambda_1 = 3$; $\lambda_2 = 46$; in the third level wavelet algorithm, $\lambda_3 = 1.8$; $\lambda_4 = 35$. In table 1, figure A is selected as the image processed.
Table 1. Comparison of different enhancement algorithms

| measure index          | Processing method |         |         |         |         |
|------------------------|-------------------|---------|---------|---------|---------|
|                        | Original A        | Histogram equalization | Soft threshold | Wavelet enhancement | Improved wavelet enhancement |
| Mean value             | 112.47            | 125.36  | 127.5   | 104.14  | 134.45  |
| Mean square error      | 35.53             | 51.32   | 46.33   | 47.33   | 46.27   |
| Contrast enhancement ratio | 1.0            | 1.16    | 1.23    | 1.28    | 1.31    |

It can be seen from Table 1 that the mean square error of the processed images increases, but the comparison between the mean values of each processing method shows that the improved wavelet enhancement algorithm is better, the contrast is improved, and there is a clear contrast before and after the processing.

The following experiment adds different Gaussian noise (0,) to the graph A, uses three kinds of methods to carry on the enhancement processing, and the post-processing SNR is shown in table 2.

Table 2. Comparison of different enhancement algorithms

| $\delta^2$ | Image enhancement algorithm |         |         |         |         |
|------------|------------------------------|---------|---------|---------|---------|
|            | Histogram equalization       | Wavelet enhancement | Improved wavelet enhancement |
| 0.01       | 12.31                        | 13.14   | 15.54   |
| 0.02       | 9.36                         | 10.22   | 12.51   |
| 0.03       | 7.76                         | 8.58    | 10.90   |
| 0.04       | 6.59                         | 7.41    | 9.73    |
| 0.05       | 5.79                         | 6.63    | 8.90    |
| 0.06       | 5.17                         | 5.98    | 8.28    |
| 0.07       | 4.63                         | 5.43    | 7.75    |
| 0.08       | 4.21                         | 4.99    | 7.35    |
| 0.09       | 3.82                         | 4.61    | 6.95    |
| 0.10       | 3.50                         | 4.29    | 6.65    |

It can be seen from table 2 that for the same $\delta^2$-improved wavelet enhancement algorithm, the signal-to-noise ratio is higher than the other two algorithms. In the experiment of image processing, it is better to choose the appropriate value to denoise the image. This method overcomes Soft Threshold Distortion and Non-Continuity of Hard Thresholds.

5. Conclusions

Aiming at the shortcomings of the soft and hard threshold functions commonly used in the image denoising process during processing, an improved threshold method are proposed to denoise, it can be found experimentally that the SNR of various methods is compared under different $\sigma^2$-noise conditions. Compared with other methods, the method proposed in this paper has improved to cut the noise efficiently, the signal-to-noise ratio and the contrast enhancement, and the RMS error has been reduced. It proves that the wavelet denoising method proposed in this paper can overcome the defect of the method of denoising in traditional algorithm in the process of image processing, and has better treatment effect for the lack of light and uneven illumination.

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