Application of Edge Preserving and Interpolation Algorithm Based on Wavelet Transformation in Mechanical Inspection and Flaw Detection

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Abstract. In mechanical inspection and flaw detection, the fault point in the image is often small, it is easy to cause the occurrence of missed detection, and due to the internal factors of the imaging system and environmental effects, the final image is often degraded, which is manifested as the deterioration of subjective vision and the decrease of actual resolution. In order to improve the resolution of the image without changing the existing imaging system and prevent the occurrence of the phenomenon of missed detection. An interpolation edge preserving algorithm based on wavelet transformation is proposed, the algorithm firstly performs edge detection and interpolation for low-resolution image, after that, the initial interpolated magnified image was decomposed by wavelet, and the low-frequency component image after wavelet decomposition was replaced by the original low-resolution image. Then, the inverse wavelet transform was carried out to obtain the high-resolution image with good edge information. The experimental results show that compared with the traditional interpolation method and wavelet interpolation method, this algorithm performs better in the edge visual effect and objective index, and it is an effective algorithm to improve the resolution of detection image.

1. Introduction

In the process of using mechanical equipment, its internal parts are subjected to various kinds of stress for a long time, which makes it gradually cause damage and anomaly. This will affect the stability of the equipment, and may even lead to equipment scrapping and catastrophic consequences [1-2]. Therefore, the periodic flaw detection of mechanical equipment is particularly important. In the flaw detection of mechanical equipment, the non-injury detection method had been widely used. The flaw points in the detected images are usually small, and the images obtained by the imaging system are often degraded, which is manifested by the deterioration of the subjective vision and the decline of the resolution, these factors make the flaw points difficult to be found. To improve the detection effect, it is necessary to magnify the low-resolution image, and the low-resolution image will often appear a series of problems such as mosaic, edge blurring after magnification, which will affect the visual effect [3]. Replacing hardware equipment to improve the quality of images is often more expensive, but converting low-resolution images to high-resolution images by software is not only less expensive, but also more
feasible. This kind of software not only can be used in fault detection, but also has important application value in grain optimization, machine vision and micro medical operation [4-5].

The methods to improve the resolution of the image can be divided into three categories: method based on interpolation, Super resolution reconstruction based on image sequence and method based on machine learning [6-8]. Super resolution reconstruction based on image sequence and method based on machine learning have better effect, but the algorithm is complex and the reconstruction of an image is time-consuming, it is not suitable for the occasion with high real-time requirement. Method based on interpolation is the simplest and the least time-consuming of the three methods. Classical interpolation methods include nearest point interpolation, bilinear interpolation and Bi-cubic interpolation [9-10]. Although the classical interpolation method can magnify the image, it is easy to appear mosaic and serrated phenomenon in the edge and texture of the enlarged image, which affects the visual effect of the enlarged image and is not conducive to the discovery of the flaw point.

This paper analyzed the shortcomings of classical interpolation methods in image magnification, and proposed an interpolation edge preserving algorithm based on wavelet transformation. The original low-resolution image is detected by edge detection, and the image is divided into different feature regions for interpolation amplification, then the initial magnified image is decomposed by wavelet transform, and the original low-resolution image is used as the low-frequency part after wavelet decomposition, and the high quality reconstructed Image obtained by wavelet reconstruction. Experimental results show that the image reconstructed by the proposed method can keep the edge information better while the resolution is improved, which is more beneficial to the observation of human eyes.

2. Classical image interpolation method and error factor analysis
The essence of the traditional image interpolation method is to estimate the unknown position data by using the data information of the existing image. The pixel at \((x, y)\) has four horizontal and vertical neighborhood pixels. Bilinear interpolation method choose four nearest pixels value, then weighted interpolation the value as interpolation point, The bilinear interpolation formula at interpolation point \(f(x+u, y+v)\) is
\[
f(x+u, y+v) = (1-u)(1-v)f(x, y) + (1-u)vf(x, y+1) + u(1-v)f(x+1, y) + uvf(x+1, y+1)
\]
\[(1)\]

\(f(x, y)\) is the pixel value of the image at pixel point \((x, y)\); \(u\) and \(v\) is the horizontal and vertical distance from the interpolation point to the pixel point \((x, y)\).

Bi-cubic interpolation use sixteen near point to calculate the interpolation point, first set the horizontal of image as direction, set every four points as interpolations to interpolate three times, then set the vertical of image as direction, set every four points as interpolations to interpolate three times. The formulation of Bi-cubic interpolation is:

The value of interpolation point is obtained from 16 adjacent points in the bi-cubic interpolation method. Firstly, the row of the image is used as the direction, every 4 points as the interpolation point perform cubic interpolation, and then the column of the image is used as the direction, every 4 points as the interpolation point perform cubic interpolation, the bilinear interpolation formula at interpolation point \(f(x+u, y+v)\) is
\[
f(x+u, y+v) = A*B*C
\]
\[(2)\]

\[A = [d(u+1) d(u+0) d(u-1) d(u-2)]\]
\[(3)\]
\[ B = \begin{bmatrix}
  f(u-1,v-1) & f(u-1,v+0) & f(u-1,v+1) & f(u-1,v+2) \\
  f(u+0,v-1) & f(u+0,v+0) & f(u+0,v+1) & f(u+0,v+2) \\
  f(u+1,v-1) & f(u+1,v+0) & f(u+1,v+1) & f(u+1,v+2) \\
  f(u+2,v-1) & f(u+2,v+0) & f(u+2,v+1) & f(u+2,v+2)
\end{bmatrix} \]  

\[ C = \begin{bmatrix}
  d(v+1) \\
  d(v+0) \\
  d(v-1) \\
  d(v-2)
\end{bmatrix} \]

\[ d(t) = \begin{cases}
  1 - 2|t|^2 + |t|^3, & 0 \leq |t| < 1 \\
  4 - 8|t| + 5|t|^2 - |t|^3, & 1 \leq |t| < 2 \\
  0, & (2 \leq |t|)
\end{cases} \]  

\( d(t) \) is interpolation kernel function.

The classical image interpolation method has the advantages of simple algorithm and easy realization, but it only considers the correlation between the adjacent points of the image pixel, and does not consider the detail feature and global correlation of the image in the edge and texture part when magnify the low-resolution image. In the process of image magnification, the detail of reconstructed image will be blurred, so it is difficult to guarantee the quality of magnified image, which is represented by mosaic and serrated phenomenon of edge and texture of image.

3. Edge preserving interpolation Algorithm

3.1. Edge detection of original low resolution image

To overcome the blurring of the edge and texture caused by the classical image interpolation method, the original low resolution image is detected by edge detection, and the image is divided into flat region and edge texture area for interpolation. The commonly used edge detection operators are Prewitt operator, Sobel operator, canny operator and so on [11-13]. The Canny edge detection operator satisfies the three criteria of high detection rate, accurate location and clear response simultaneously, and has good robustness to the error, so this paper chooses canny operator to detect the edge of the original low-resolution image. Figure 1 is a sample diagram of a building edge detection.

(a)Original image  
(b)Edge detection image

Figure 1. Edge detection sample diagram.
3.2. Adaptive interpolation for different regions of Image

By edge detection, the original image can be divided into flat region and edge texture area, the interpolation value of each region is obtained by using the different regions in which the pixel points of the image are located [14]. Using the edge enhancement function (7) to obtain the edge texture portion of the image.

\[
E_{edge}(u,v) = \left[ \left( f(u + 1, v) - f(u,v) \right)^2 + \left( f(u,v + 1) - f(u,v) \right)^2 + \left( f(u - 1, v) - f(u,v) \right)^2 + \left( f(u,v - 1) - f(u,v) \right)^2 \right]^{\frac{1}{2}}
\]

(7)

\(E_{edge}\) is the edge texture information of the image.

Then the original low resolution image after edge detection is amplified by nonlinear interpolation using interpolation kernel function, the initial interpolated magnified image is

\[
\hat{F} = \frac{1}{k} \sum_{a,b \in \Omega} \left( f(b) + \lambda_u E_{edge} \right) d(\|a-b\|)
\]

(8)

\(d(t) = \begin{cases} 
1 & t = 0 \\
\left[ a \sin(\pi t) \sin(a \pi t) \right]/(\pi^2 t^2) & 0 < |t| < a \\
0 & \text{other} 
\end{cases}
\]

(9)

\(\hat{F}\) is the initial interpolated magnified image; \(a\) and \(b\) respectively represents the corresponding coordinate positions of the original low resolution image and the initial interpolated magnified image; \(d(t)\) is nonlinear interpolation kernel function.

3.3. Two-dimensional discrete wavelet transform

Because the region feature of the original low resolution image was considered for nonlinear interpolation, the initial interpolated magnified image edge and texture details can be preserved better than the classical image interpolation method, but some detail information will still be lost in the interpolation process. To enhance the information of reconstructed image, the initial interpolated magnified image is decomposed by wavelet transform, after the decomposition of the \(j + 1\) layer of wavelet, the two dimensional approximation image of the \(j\) layer can be expressed as

\[
A_j F(x,y) = A_{j+1} F(x,y) + D^1_{j+1} F(x,y) + D^2_{j+1} F(x,y) + D^3_{j+1} F(x,y)
\]

(10)

\[
\begin{align*}
A_{j+1} F(x,y) &= \langle F(x,y), \phi_{jk} (x) \phi_{jk} (y) \rangle \\
D^1_{j+1} F(x,y) &= \langle F(x,y), \phi_{jk} (x) \psi_{jk} (y) \rangle \\
D^2_{j+1} F(x,y) &= \langle F(x,y), \psi_{jk} (x) \phi_{jk} (y) \rangle \\
D^3_{j+1} F(x,y) &= \langle F(x,y), \psi_{jk} (x) \psi_{jk} (y) \rangle
\end{align*}
\]

(11)

Four parts obtained after decomposition, \(A_{j+1} F(x,y)\) is the low-frequency component of the decomposed image, which contains most of the energy of the image \(A_j F(x,y)\) of the previous level; \(D^1_{j+1} F(x,y), D^2_{j+1} F(x,y)\) and \(D^3_{j+1} F(x,y)\) are wavelet sub-band coefficients after image decomposition, which reflect the information of image in horizontal, vertical and diagonal directions.

In this paper, one-level wavelet decomposition of the initial interpolated magnified image \(\hat{F}\) is carried out, The low frequency part \(A_1 F(x,y)\), high frequency part \(D^1_1 F(x,y), D^2_1 F(x,y)\) and
$D_1^1 F(x, y)$ are obtained. Perform linear transformation on the initial low resolution image, and replace $A_i^1 F(x, y)$ as the new low-frequency component. Using the new low-frequency component and wavelet sub-band coefficients $D_1^1 F(x, y)$, $D_2^2 F(x, y)$ and $D_3^3 F(x, y)$ to reconstruct the high resolution image by inverse wavelet transform, to increase the information of the reconstructed image.

4. The Experimental results and analysis
To illustrate advantages and effective of the proposed edge preserving and interpolation algorithm, using “westconcordorthophoto” image which size is $364 \times 366$ as the original high resolution image in the experiment. After 2 times down-sampling of the image, the classical bi-cubic interpolation method and the proposed algorithm are used to reconstruct the low-resolution image. Down-sampling image and reconstructed images is showed in Figure 2. Reconstructed images uses PSNR (peak signal to noise ratio) and SSIM (structure similarity image measure) for evaluation, the results of the reconstruction are as follows

![HR image - Down-sampling image - Bi-cubic method - Proposed algorithm](image)

Figure 2. Reconstructed results of down-sampling image

|                      | PSNR | SSIM  |
|----------------------|------|-------|
| bi-cubic method      | 24.215 | 0.4584 |
| proposed algorithm   | 24.784 | 0.5763 |

From the original high-resolution image, the reconstructed image obtained by bi-cubic interpolation method and proposed algorithm in this paper, we can see by considering the global correlation between the edge and texture part of the image, and using wavelet transform to increase the information lost in the nonlinear interpolation, the fuzzy phenomenon in the edge and texture part of the image was obviously improved compared with the classical bi-cubic interpolation method. The objective evaluation index also shows the effectiveness of the proposed algorithm in this paper.

5. Conclusion
In the field of mechanical inspection and flaw detection, the image interpolation amplification technology can solve the problem of missed detection caused by small fault points in the detection images. To overcome the shortcoming of the classical interpolation method, the low resolution image was divided into flat region and edge texture area for nonlinear interpolation amplification after edge detection, and reconstructed the high resolution image by replace low-frequency component with the initial low resolution image in wavelet transform to increase the information of the reconstructed image. The experimental results showed that the proposed algorithm can effectively overcome the shortcomings of the classical interpolation method, the obtained image has better objective index, and the visual effect is closer to the original high resolution image. It provides an effective algorithm for fast improving the resolution of existing images.
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