

## RESEARCH ON AUTOMATIC INSPECTION TECHNIQUE OF REAL-TIME RADIOGRAPHY FOR TURBINE-BLADE

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**Abstract:** To inspect turbine blade automatically, with a real-time radiographic system based on X-ray flat panel detector, computerized defect extraction technique is studied on the basis of characteristics of turbine blade's digital radiographic images. At first, in the light of a variety of gray-level in a turbine blade's digital radiographic image, it is divided into six subareas. An adaptive median filter is used to smooth defects in each subarea. Then, the filtrated image is subtracted from the raw image and a difference image with flat background and outstanding defects is obtained. After that, thresholding is applied to the difference image and defects in the turbine blade become obvious. Later on, a morphological opening is used to realize noise reduction. In order to ensure the accuracy of defects, a region growing method is adopted to reconstruct the defects. Finally, the feature data of defects are extracted. The comparison between computerized feature extraction results and human interpretation results indicates that the method mentioned above is effective and efficient, which will lay a good foundation for automatic inspection of turbine-blade with X-ray.

**Keywords:** real-time radiography; self-adaptive median filtering; defect extraction; image processing; nondestructive testing

**Introduction:** As a traditional inspection technique of nondestructive testing for industrial equipments and components, the human interpretation of radiographic films can locate any cavities, inclusions, porosities, etc, which may have been formed during the manufacturing or machining process exactly or directly<sup>[1]</sup>. But this is a hard and difficult task when a great number of defects are to be counted and calibrated. Radiographic testing with film is also an expensive and time-consuming technique (exposure time and development of the film). It is known that several experts do not have the same opinion on a given film, and even the same expert might have a different report at the beginning or the end of a workday. With the development of computer technology, image processing and pattern recognition technology, some attempts have been made to automate the inspection process with computer.

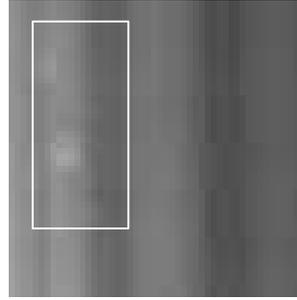
At the end of 1990s, the successful application of X-ray flat panel detector in real time imaging system made it possible to acquire digital images with high resolution. These inspection images can be processed directly with computer, which establishes a basis for intelligent recognition of inspection images of important parts in aeronautic and astronautic devices.

In this paper, the possibilities are investigated of automatic defects extraction of X-ray inspection images of turbine blade acquired with real time imaging system based on Flat Panel Detector, and the method is researched of extracting defect feature by analyzing the characteristics of inspection images of turbine blade to solve the conflict between precision of defects and processing speed and provide exact data to intelligent recognition of defects.

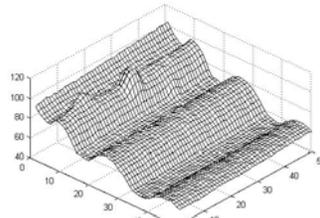
**Analysis of Digital Radiography (DR) Image of Turbine Blade:** Figure 1 is a DR image of a turbine blade acquired with a real time imaging system based on flat panel detector. Figure 2 is a magnified part of the image of the turbine blade that contains defects. Characteristics of a turbine blade image is as follows: 1) Contrast is low; 2) Edges of defects are blur (there are two rectangle-shaped defects in Figure 2); 3) There is a gray-level wave along different direction in different area, such as a vertical gray-level wave in rabbet (Area A in Figure 3) and a horizontal and sloping gray-level wave in turbine blade body (Area D and E in Figure 3); 4) Defects and its background have the same gray-level sometimes; 5) There are high gray-level defects (such as porosities and flaws) and low gray-level defects (such as mantel inclusions ).



Fig.1 Inspection image of turbine blade



a) 2-D image



a) 3-D image

Fig.2 Image of a part of defective turbine blade

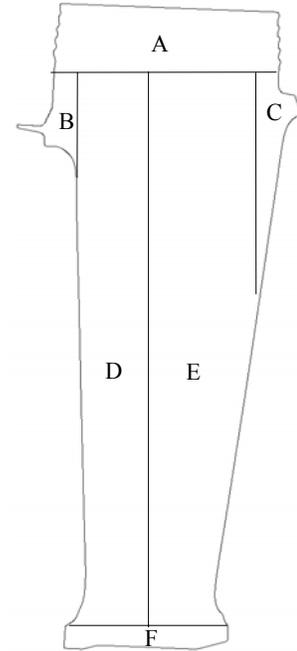


Fig.3 Subarea of turbine blade

**Solution:** From aforementioned analysis, gray-level variety in a turbine blade's DR image is complicated and the changing direction of the gray-level of image background is different in different areas. Accordingly, eliminating background was adopted to extract defects. In accordance with the feature of gray-level wave, the turbine blade area of the inspection image is divided into six subareas. In each subarea, at first, a median filter based on scan-line is applied to smooth the high frequencies of the image (defects and noise) while preserving the low frequencies. Then, the filtrated image is subtracted from the raw image to retrieve the high frequencies without the low ones. After that, a global threshold is applied to separate defects and background. Finally, the feature data of defects is extracted.

**Realizing Steps:** 1) Edge Extraction. There are a turbine blade's image and a white background in the inspection image. Defects only exist in the turbine blade's image area. Contour of a turbine blade is extracted by edge detection. Restricting the processing field in the turbine blade image area by the contour can decrease processing time. 2) Gray-level Enhancement. The gray-level of the turbine blade's image area in raw inspection image is low, its dynamic range is narrow and contrast is poor. Therefore, the grey-levels must be stretched to the whole dynamic range to improve quality of the image. The following Formula (1) is applied to enhance the gray-levels.

$$y = \begin{cases} cx & x \in [0, a] \\ \frac{255-ac}{255-a}(x-255) + 255 & x \in (a, 255] \end{cases} \quad (1)$$

Where  $x$  is gray-level before enhanced,  $y$  is gray-level after enhanced,  $c$  is a coefficient and  $c > 1$ , parameter  $a$  is threshold of the inspection image.

3) Background Elimination. A filter is applied to the enhanced image to smooth the defects. Then the filtrated image is subtracted from the enhanced image and a difference image with outstanding defects is obtained. Many kinds of filters can be used, but median filter can be operated simply and rapidly, and it is self-adaptive easily. When a one-dimension median filter is used, not only are the defects with high gray-level smoothed, but also the defects with low gray-level are smoothed. Mean and morphologic filters can't achieve the same smoothing effects as median filter does. In order to smooth defects exactly and rapidly, subarea and adaptive median filtering are put forward. The turbine blade image area is divided into six fields as Figure 3. Median filtering based on scan-line

along different direction is applied in each subarea: horizontal filtering is applied in subarea A, B and C, vertical filtering in subarea D and F, and filtering along with air exit hole in subarea E. When the scan-line direction based median filter is applied, the filter length is adjusted with the size of defects adaptively. This kind of median filtering can smooth defects completely. If there is not any defect in a scan-line, no filter is applied. The procedure to determine the length of filter is illuminated in Figure 4. At first, search the extremum points  $cx$  of gray-level curve in a scan line. Then search the nearest trough leftwards to  $lx$  and rightwards to  $rx$ ; work out gray-level difference  $t_1$  between  $cx$  and  $lx$ , and  $t_2$  between  $cx$  and  $rx$ :  $t_1 = gray(cx) - gray(lx)$ ,  $t_2 = gray(cx) - gray(rx)$ . Suppose  $t_{Defect}$  is a threshold to distinguish background and defects,  $t_{Noise}$  is a threshold to distinguish defects and system noise. If  $t_{Defect} \leq \min(t_1, t_2) \leq t_{Noise}$  length of filter is  $2(rx - lx) + 1$ , otherwise length of filter is 0. Above mentioned researching cycle is repeated from  $rx$  to the end of the scan line and the longest filter is applied to the whole scan line. In order to process cross-subarea defects correctly, firstly, search the last extremum point of the previous scan line from the starting point of the current scan line, and determine the length of filter; then process the current scan line starting from the extremum point to the end of current scan line; finally, search the first extremum point of the next scan line from the end point of current scan line and determine the length of filter. Subtract the filtrated image from the enhanced image to obtain the difference image. Figure 5(a) and (b) show the result, from that it can be seen that the background is flat and the defects are outstanding.

4) Thresholding. According to histogram of different images, select a proper threshold to determine each pixel of the image whether it belongs to defects or background, and produce a corresponding binary image. Selection of threshold is crucial to segment defects. If threshold is too high, more defect pixels are judged as background. Contrarily, the result is just reverse. This will affect the shape and size of segmented defects. The background of the difference image is flat so that it is possible to apply a global threshold to separate defects from background. This gives a binary image. Threshold value based on gray-level histogram can be applied to determine the threshold value exactly (such as Maxentropy<sup>[2]</sup>).

5) Noise Reduction. After thresholding, defects are separated from background, but noises are separated with defects inevitably. The binary image is filtrated by morphological opening operation with 3+3 structuring element, which can protect defects<sup>[3]</sup>.

6) Defects Growth. The area of the defects can be affected by the noise reduction step. To improve the detection, a region growing method is applied with respect to enhanced image. There are many growth criteria, one of the simpler methods is comparison of the grey-levels. A brief description of defects growth is given below.

6.1) Marking. 4 neighborhoods marking algorithm is applied to the binary image (the position of 4 neighborhoods is shown in Figure 6) to scan the image pixel to pixel and a sequence number to every pixel are obtained. Suppose the gray-level of the background is 0, gray-level of defects is 255, and  $f(x, y)$  is the gray-level of current pixel,  $l(x, y)$  is the sequence number of current pixel,  $f(i)$  are gray-level of neighborhood pixels of current pixel and  $l(i)$  is the sequence number of them, where  $i=1\sim 4$ . The algorithm of 4 neighborhoods marking is described as following. (1) Suppose  $label = 0$ ; (2) Scan binary image from up to bottom and from left to right. If  $f(x, y) = 255$ , investigate the 4 neighborhood pixels

- a) If there is not any defect pixel in the 4 neighborhoods mark a new sequence number to the current pixel, that is  $label = label + 1, l(x, y) = label$ .
- b) If there is only one defect pixel in the 4 neighborhoods, mark the same sequence number to the current pixel as the defect pixel, that is  $l(x, y) = l(i)$ .
- c) If there are more than one defect pixels in the 4 neighborhoods give the minimum sequence number of the 4 neighborhoods to the current pixel, that is  $l(x, y) = \min l(i)$ .

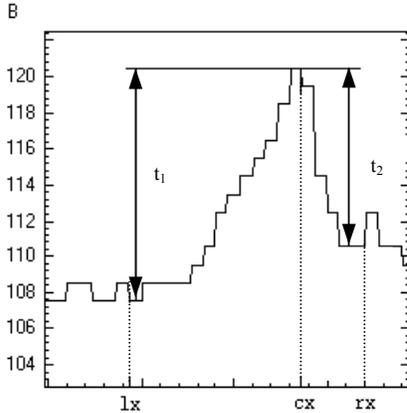
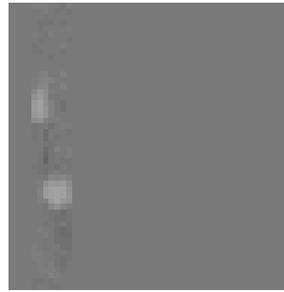
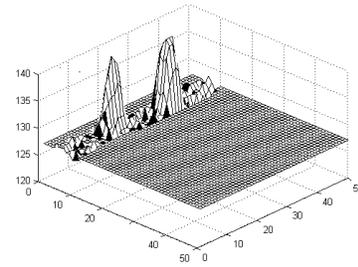


Fig.4 The gray-level curve of scan line AB



a) 2-dimensional display of difference image



b) 3-dimensional display of difference image

Fig. 5 Defect image after background elimination

$(x-1, y-1)$	$(x, y-1)$	$(x+1, y-1)$
$(x-1, y)$	$(x, y)$	

Fig.6 Position of 4 neighborhood pixels

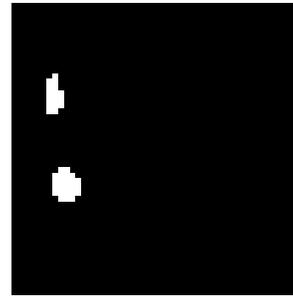


Fig. 7 Grown defects

6.2) Neighbor region uniting. Unite neighboring regions with different sequence number into one region and make all pixels in one region have the same sequence number. 6.3) Original growing region. Work out the centre and original enclosing rectangle of defect fields by making use of the sequence number of defects. If the centre is inside the defect, the centre and its 8 neighborhoods construct the original growing region, otherwise, the original growing region is determined in accordance with the centre and the shape of the defect, and it is located in the central section of defect at full steam. 6.4) Defect growing. Begin with original growing region. After several enclosing rectangle growing cycle<sup>[4]</sup>, the defect is grown again. The grown defects are shown in Figure 7.

7) Feature extraction. The extracted feature parameters as follows: 7.1) Centre of gravity  $M(x_0, y_0)$ :  $x_0 = \frac{1}{n} \sum x_i$

$y_0 = \frac{1}{n} \sum y_i$ , Where  $n$  is the number of pixels in a defect,  $(x_i, y_i)$  is the coordinate of defect pixel; 7.2) Area A: the number of pixels in a defect. 7.3) Long diameter L and short diameter S: the length and width of enclosing rectangle with the minimum area of the defect region. 7.4) Perimeter P: track the boundary of defect using 8 neighborhood algorithm<sup>[5]</sup> and record the boundary information data in freeman directional chain-code (shown in Figure 8) according to the trend of the boundary. Odd number chain-code corresponding length  $\sqrt{2}$ , even number corresponding length 1, the sum of all chain-code length of a boundary is perimeter, the formula of perimeter as follows:

$$P = \frac{\sqrt{2}+1}{2}n - \frac{\sqrt{2}-1}{2} \sum_{i=1}^n (-1)^{C_i} \quad (2)$$

Where  $n$  is the number of pixels in a boundary,  $C_i$  is the directional number of chain-code  $\square 0 \sim 7 \square$ . The extracted feature data is shown in table 1.

Table 1 Feature data of defects corresponding to Fig.7

Number of defect	Center	Perimeter	Area	Long diameter	Short Diameter
1	£ 126,840£ ©	15.66	16	7	3
2	£ 128,855£ ©	16.48	24	6	5

3	2	1
4	(x, y)	0
5	6	7

Fig.8 Freeman position coding

**Conclusions:** X-ray digital radiography and intelligent recognition of defects are basis of automatic inspection. An effective method for automatic defect extraction in inspection image of turbine blade is developed in the paper. The method put forward in the paper is effective and can solve the conflict between processing speed and precision of extracted defects. Some conclusions are gotten as follows: 1) The method can extract defect information quickly and accurately, and solve the conflict between processing speed and precision of extracted defects. 2) The background of defects is eliminated by adaptive median filtering, and a region growing method is applied to grow defects, which ensures that the extracted defects are accurate in size and shape. 3) The processing region is limited inside the turbine blade area by extracting the contour accurately, which decreases the processing time consequently.

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