THE APPLICATION OF DICTIONARY-BASED PROBABILTY RELAXATION IN CRACK EXTRACTION OF INSPECTION WELD IMAGE

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ABSTRACT: *An algorithm used to inspect and extract crack defects from weld image is developed in this paper. In this algorithm the weld image is dealt with based on Laplacian operator with offset, and aiming at to the processed image 12 dictionary models are established with allowable structure. Effective searching method is provided based on the application of dictionary and more and more context-dependent information is extracted from neighborhood context. Then noise can be reduced effectively and crack defects can be extracted. Experimental results show that longitudinal crack can gain better uninterrupted edges and better clear outline using this algorithm. This algorithm possesses better noise resistance and is a class of inspection method of faint crack.*
Keywords: *Dictionary; Probabilistic relaxation; Weld; Crack; Extraction*

1. INTRODUCTION

Since weld failure can lead to catastrophic events in many fields, such as pressure vessels, power plants and aeronautic equipment, welded structures often have to be tested nondestructively. Being easily applicable to check objects that possess different shapes, sizes and physical features, RT (Radiographic testing) is one of the most widely used inspection techniques. In the case welded defects are checked out, the classs and sizes of them should be determined because they are useful for the evaluation and judgment of welded quality. Qualitative and quantitative analysis of welded defects is the base of the determination nondestructive workers make.

During the course of the weld, crack is a class of familiar and harmful technical fault. In order to improve the quality of welded technique and the useful life of service of welded workpiece and avoid the occurrence of serious accidents, distinguishing and overcoming welded crack is one of the urgent problems to solve. However it is difficult to judge crack defects shadow inside X-ray image correctly because there are various cracks that exist most parts of the weld. Furthermore crack is a kind of slot defect and displays faintly on the weld image, and at some time, there is a long and discontinuous crack on the weld image. And sometimes crack becomes fuzzy and cannot form the object with certain contrast ratio, thus it is not easy to find out when defect recognition.

Edge-labeling using probability relaxation is an excellent postprocessing technique that uses neighborhood information to inspect and label. To preprocessed image (initial edge inspection), the whole information of edges is used to harmonize and enhance initial inspection result. At the same time it can enhance the real edges, reduce noise and avoid edge losing and deformity. Edge-labeling using probability relaxation has been used to lots of image processing problems, such as edge detection[1~4], image segmentation[5], edge enhancement[6], pixel classification[7] and image restoration. Since narrow defects are approximate to the image edge, crack defects can be extracted and determined using the method of edge processing.

In this paper the crack-class defect extraction is studied using the method of dictionary-based probability relaxation. Through making use of the relative information of pixels, every time at a certain range of one pixel the relative information is considered. After several iterations rough image preprocessed is harmonized and modified, and at the same time noises are reduced. Finally, find out the labels of every pixel and determine accurate crack image. Section 2 presents the some preprocessing methods, including the classification of defect classes and the image processing algorithm of crack-class defects. Section 3 presents the extraction algorithm of faint crack based on the method of probability relaxation, including the theory of probability relaxation, dictionary-based model and dictionary-based probability relaxation. Section 4 presents the experiments and their results. Section 5 is the conclusion of the whole paper.

2. THE PREPROCESSING OF X-RAY INSPECTION WELD IMAGE

There are so many classes of defects inside weld, such as pore, slag inclusion, lack of fusion, lack of penetration and crack and at the same time there is no general algorithm that can adapt to all images and most of them are developed aiming at to certain problems. In order to extract all kinds of defects correctly, weld image is preprocessed based on waveform analysis. According to the waveforms the weld that contains crack-class defects and the other class defects can be classified. After that, different algorithms are adopted to different segmentation processing (inside the weld there may be crack-class defects and non-crack defects at the same time, so the different method is adopted to corresponding case).

In this paper if the width of the trough on the row gray-scale distribution curve is less than 6 pixels, the defect is regarded as crack-class defect. Since the crack-class defect is so small, the method with general threshold can not be used. Those operators, such as Sobel, Roberts, Prewitt and Kirsck, possess the function of smoothness. On the time of differential calculation the image can be smoothed and to tiny defects the edges will become fuzzy, even disappeared. Although Laplacian operator is considerably sensitive to the noise, it can be used to inspect lines and produce isolated points. In this case defects less than or equal to 6 pixels are regarded as lines. Laplacian operator is defined as follows:

$$\nabla^2 f(i,j) = f(i+1,j) + f(i-1,j) + f(i,j-1) + f(i,j+1) - 4f(i,j)$$

Since pixel gray-levels usually are unsigned numbers and value range is from 0 to 255, the processed results are positive or negative according to the definition of Laplacian operator. If the value is negative, it will display as 0. This way will decrease the contrast of inspected results, so when display an offset can be added. The offset is:

$$L^*(i,j) = 4f(i,j) - f(i+1,j) - f(i-1,j) - f(i,j-1) - f(i,j+1) + Offset$$

Different offset will produce different display content and obtain different display effects. Besides, in order to improve the contrast of second differential, the processed gray-level is multiplied by a magnified coefficient k. So the operator used to crack-class defects inside weld image of X-ray inspection is defined as follows:

$$L^*(i,j) = k\{4f(i,j) - f(i+1,j) - f(i-1,j) - f(i,j-1) - f(i,j+1)\} + Offset$$

Experimental results show that when k = 4 and *Offset*=128 the better effects can be obtained. Figure 1 shows that the weld image containing crack-class defects and its inspected image using Laplacian operator with offset.

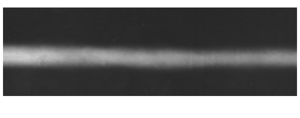

Figure 1. Original and Crack edge detection image using Laplacian with offset

After processing with the operator mentioned above, the crack is very clear. Although there exist lots of noises, the difference of gray-level between crack, noise and background is considerable. Some part of the crack is very faint, but it is still uninterrupted, just because the value is very small. Thus the processed crack will possess these features: 1) there are lots of noises, but they are all isolated points or isolated blocks (small blocks); 2) every interrupted crack is bigger than isolated points or isolated blocks; 3) crack extends directionally. In order to distinguish crack from noise, the method of edge-labeling dictionary-based probability relaxation is adopted to reduce the noise and extract crack-class defects according to the characteristic that in some part crack is uninterrupted and directional.

3. DEFECTS EXTRACTION OF FAINT CRACK-CLASS BASED ON THE ALGORITHM OF DICTIONARY-BASED PROBABILITY RELAXATION LABEL

The probability relaxation label starts with initial labeling probability, then delivers local or the whole relative information among associate objects. Through harmonizing and modifying the initial labels, find out the estimation values of the biggest posterior probability (MAP), reduce noises and then determine one and only label to every object.

3.1. The Theory of Probability Relaxation

Suppose there are n objects A_i, i=1,2,…, n, which are classified as m classs, C_j, j=1,2, …, m, and the classification courses affect each other. Suppose $P_{ij}^{(0)}$ is event and $A_i \in C_j$ initial probability. Repeat it and then obtain probability distribution corresponding to restrict condition as the base of classification. Then linear combination is developed just as:

$$Q_{ij}^{(r)} = \frac{1}{n-1}\sum_{h \neq i}\sum_{k=1}^{m} c(i,j;h,k) P_{hk}^{(r)}$$

Here c(i, j; h, k) is the consistent coefficient between event $A_k \in C_k$ and event $A_i \in C_j$, and satisfies the relation $|c(i,j;h,k)| \leq 1$, at the same time:

$c(i,j;h,k) > 0 \leftrightarrow A_h \in C_k$ and $A_i \in C_j$ consistent;
$c(i,j;h,k) < 0 \leftrightarrow A_h \in C_k$ and $A_i \in C_j$ non-consistent;
$c(i,j;h,k) = 0 \leftrightarrow A_h \in C_k$ and $A_i \in C_j$ independent;

So the iteration probability is as follows:

$$P_{ij}^{(r+1)} = \frac{P_{ij}^{(r)}[1+Q_{ij}^{(r)}]}{\sum_{l=1}^{m} P_{il}^{(r)}[1+Q_{ij}^{(r)}]}$$

Here r is the iteration superscript.

Since every iteration should base on the class one pixel belongs to determined by the equation above, the pixels are updated according to a certain threshold and the updated image is reserved as the result of the iteration, which is for the use of the next iteration. After several iterations more and more contexts are extracted from the neighborhood step by step.

Classifying defects using the method of probability relaxation, the results often are restricted by compatibility and not sensitive to noises. When compatibility rule and coefficient are selected appropriately, better effects can be obtained. Compatibility rule and coefficient should be selected based on actual problems.

To the whole image through introducing Markov field contexts can be constrained inside a small window, that is to say, they only have relationship with their neighbor pixels. Then a structure dictionary is built in the 3×3 neighbors of a pixel. At the same time the method of probability relaxation label is used to modify the error-labeling pixels, which can reduce noise and obtain edge figure of given image.

3.2. The Algorithm of Dictionary-Based Probability Relaxation Label

3.2.1 Estimation of initial label probability

During the edge detection every pixel inside image possesses two labels: edge and non-edge in the label set. Relaxation label is to designate each pixel as edge or non-edge label. The method of probability estimation for image initial label is given as follows:

(1) Preprocess weld image with crack-class defects based on section 2.

(2) Judge every pixel on preprocessed image. If the number of uninterrupted cross-zero is less than 5, these pixels will be ignored (set their gray-levels as 0), or they will be remained.

(3) Find out no cross-zero from preprocessed image and label their probability $P\{x_i=edge\}=0$.

(4) The probability calculation of cross-zero is just as follows:

Use the non-preprocessed image as original image and calculate gray-level difference C_{xi}, C_{yi} of neighborhood pixels on X and Y orientation.

$$C_i=\max\{|C_{xi}|, |C_{yi}|\}$$

Since the contrast between weld and background is not great, differential values of processed image are all small. So edge probability can be defined as:

$$P\{x_i = edge\} = \begin{cases} 0 & ,C_i \le 6 \\ 0 & ,|C_i| < n_T \\ 1 - C_i / C_m & ,other \end{cases}$$

Here C_m is the maximum of gray-level difference matrix and n_T is the numerical threshold of gray-level difference.

$$P\{x_i=non\text{-}edge\}=1-P\{x_i=edge\}$$

3.2.2 The determination of initial MAP label

According to the rule of MAP initial MAP label of pixel i is shown below:

$$x_i = \begin{cases} edge & ,P\{x_i = edge\} \ge P\{x_i = non\text{-}edge\} \\ non\text{-}edge & ,other \end{cases}$$

3.2.3 Dictionary-based model

During the course of probability relaxation the size of object neighborhood structure is extremely less than the one of the whole object set, usually 3×3 or 5×5. Even it is a 3×3 neighborhood structure, the number of various structures is still large. However most of them are ideal and impossible. If there is only one dictionary-based structure that can contain all allowable structure, the method of relaxation label can have good effects. That is to say, dictionary-based method can provide an effective searching method. During the edge detection, the criterions that are used to judge allowable structure are: (1) edge is closing; (2) the width of the edge is one pixel; (3) the edge is uninterrupted. Based on these criterions, when the object is the central pixel, 12 basic allowable structures corresponding to it are shown in figure 2.

To the structure 3×3, if the orientation is ignored there are 41 allowable structures, each of which possesses $\frac{1}{41}$ probability.

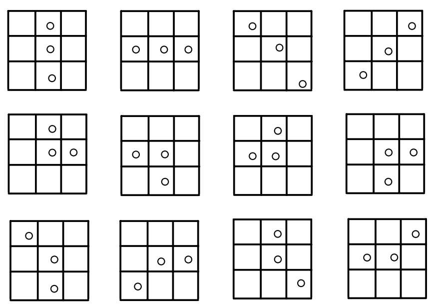

Figure 2. Basic allowable structures formed dictionary

3.2.4 The description of algorithm

Using the method of dictionary-based probability relaxation labeling to crack-class defect inspection, firstly according to the waveform weld images are classified and preprocessed based on Laplacian operator with offset, then build basic dictionary at 3×3 neighborhood and reduce noise using the method of probability relaxation labeling, which consists of the following steps:

(1) According to chapter 3.2.1 and 3.2.2 initialize labeling probability estimation and determine MAP label.

(2) Implement the algorithm of relaxation conversion according to the dictionary determined in section 3.2.3.

(3) Determine MAP labeling according to step 2. Judge whether it converges. If not, turn to step 2 and continue to iterate.

(4) Extract edge image.

4. EXPERIMENTAL RESULTS

The algorithm of dictionary-based probability relaxation labeling can make full use of the relatiive information among pixels, and the one of certain range of single pixel is considered every time. Through iteration, the rough edge inspected initially can be harmonized and modified, and finally the label of every pixel can be determined and accurate edges can be obtained. The initial values determined by labels have great effects on the ability of noise-resistance and the edge detection quality of the algorithm.

Figure 3 show the original image with crack-class defects and its processed image using the method of probability relaxation 10 times. Seeing from the processed image, uninterrupted edges can be obtained using the context of neighborhood labeling, which can be displayed through crack line itself. Figure 4 is the processed image after iteration 5 times, which contains more noises compared with Figure 3 because of not enough iteration.

Figure 3. Processed crack-class image after iteration 10 times

Figure 4. Processed crack-class image after iteration 5 times

5. CONCLUSIONS

Cracks are always the defects whose widths are small and changeable and present linear obviously, so they can be processed using Laplacian operator with offset firstly, and then processed with the algorithm of probability relaxation. Through iteration those noises of single point produced by Laplacian operator can be reduced and uninterrupted edge can be obtained, which is an effective inspection method of crack-class defects with faint display. Experimental results show that:

(1) The method of dictionary-based probability relaxation labeling possesses better noise-resistance.

(2) The method of probability relaxation labeling can get uninterrupted edges and clear outline.

(3) It is important to determine the initial labeling estimation.

(4) The method of dictionary-based probability relaxation labeling has better effects on edge detection with faint display.

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