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Development of Visual Inspection System based on Vector Analysis Technique

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Abstract

The present paper proposes a new concept of image processing method based on vector representation for visual inspection test. The method was applied to detect defects and extract their profiles from digital 2D image of welded rough surface of the structures aiming at the development of automated visual inspection system. The potential availability of the new technique based on vector representation of digital image was investigated through welding defect type recognition problem. It was confirmed that the method gives flexible and useful algorithms for detection and identification of small defect in noisy images. The technique proposed in this paper can be widely applied to various kinds of edge extraction or shape recognition in ambiguous boundary on rough texture.

1 Introduction

Visual inspection test is widely used for structure integrity check in various phases of plant construction and maintenance. Most of current visual inspection depends on expert's skills since automated small defect detection from rough surface was difficult for conventional image processing techniques. However, indirect visual inspection often cause difficulties in identification of defects even for trained inspector due to the effect of reflection and shade on welded surface condition[1]. In visual inspection of the welded surface of material, Skilled inspector check the existence of defects like crack or porosity due to inappropriate construction.

On the other hand, aiming at future plant life extension, necessity of in service inspection is getting higher even after installation for a longer period of time to assure the reliability of the structures periodically. In present status, direct visual inspection or indirect visual inspection using video images is widely applied to these types of inspection. In case of direct visual inspection, skilled inspector shows remarkable skill by observing various features in surface texture of welded material in a synthetic manner and adaptively recognizing defect as a cluster of shading in certain area. As the performance of inspection strongly depends on the inspector's skill, efficiency and rationality of the inspection procedure is regarded as a key problem for the automation.

In addition, aging of skilled inspector and shortage of inspectors are also serious problems in workshops. In case of indirect visual inspection that uses camera and video images unflatness of the welded surface that reflects light randomly cause misjudgment even by skilled inspectors.

To overcome problems described above, we have been developing the technique for the automation of visual inspection using 3D digital image processing method[1][2]. Utilization of the methodology to reconstruct the 3D shape of the surface is helpful because it is possible to distinguish defect from the shade on the surface. Efficient and correct inspection scheme must be taken into account to apply this 3D reconstruction technique. For the efficient application of the techniques, the following defect recognition strategy must be introduced, that is, high speed defect area extraction based on 2D image processing to full inspection area detailed analysis based on 3D shape reconstruction to the extracted area.

In this paper we investigated the efficient defect extraction method based on 2D image prior to 3D surface shape reconstruction. In the following sections rotation vector representation of image is described, which regards intensity of a pixel in image as one component of vector potential[3]. The algorithm of defect recognition, separation and outline

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extraction based on the vector analysis is addressed. The performance of the proposed method is also estimated through defect identification experiment with welded test pieces.

2 Algorithm

After loading image of welded surface of material to be tested, the adopted procedure of the defect extraction from a surface image consists of five subprocedures listed below:

1. Rotation vector calculation
2. Thinning considering vector direction
3. Outline segmentation and connection
4. Defect area extraction
5. Defect type recognition based on multiple feature estimation

In the following section each of the process is described more in detail.

2.1 Rotation Vector

Vector representation of an image, gradient, rotation, divergence and Laplacian is defined by regarding intensity of an pixel as scholar potential or one component of vector potential[3]. In the following analysis we focused on rotation vector operation and applied to defect extraction from the digital image of welded surface. According to vector field theory, rotation vector $R_{i,j}$ at pixel (i,j) , one of such vector analysis, can be expressed as follows($I_{i,j}$ is intensity at pixel (i,j)):

$$R_{i,j} = (\frac{I_{i,j+1} - I_{i,j-1}}{2}, -\frac{I_{i+1,j} - I_{i-1,j}}{2}) \qquad (1)$$

Rotation vector representation corresponds to the differential operation with neighboring four pixels. The length of the vector is the same as gradient vector but the direction is perpendicular. Around the area where the intensity of the neighboring pixels changes , the direction of the rotation vector is parallel to the outline of the darker area. Therefore it is possible to extract outline information by combining the pixels at which direction of rotation vectors are similar. An example result of rotation vector calculation for a magnified defect image is shown in Figure 1. It is easy to recognize from the figure that the direction of the rotation vector is along with the edge of the defect on welded surface, and distribute around the edge in clockwise direction to the center of defect. According to these characteristics, it is possible to extract outline information of the defect by connecting neighboring pixels, in which direction of the vector is similar.

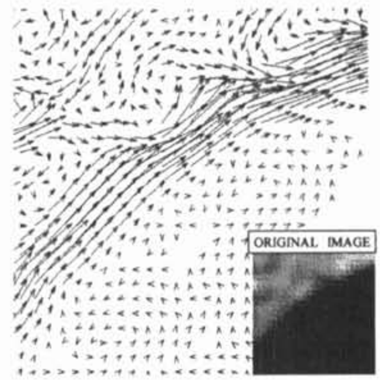

Figure 1. : Rotation vector representation of welded surface image around crack

2.2 Thinning Outline of Defect

After the rotation vector operation, the outline of the defect is extracted by thinning the outline based on the binary image produced by AND operation between intensity and vector length for each pixel of the original image. By ordinary thinning operation it is usually difficult to extract outline of defect like hair crack properly and the defect becomes just a simple line. In order to avoid such information loss, masking operation based on the vector direction prior to thinning was adopted. The procedure is illustrated in Figure 2. The extracted binary image is cluster of pixels, as shown at the top of figure 2. Next the cluster is divided into four clusters, according to the direction of the vector. Partial outlines are then extracted by thinning processing for these four clusters. Finally the partial outlines are overlapped and outline of the defect is extracted.

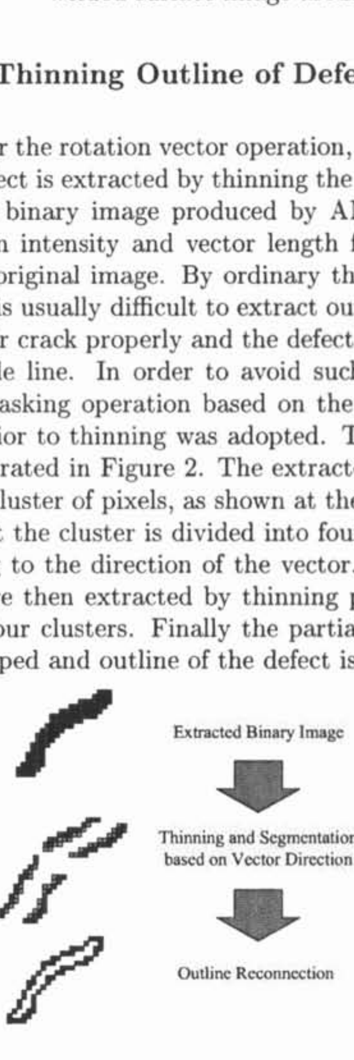

Figure 2. : Outline thinning procedure

2.3 Outline Segmentation and Connection

After thinning the extracted lines, direction for all extracted lines are estimated based on the direction of rotation vectors on the segments. Segmentation of lines are performed by searching all edge pixels and junctions. The direction of the segment is estimated by comparing the polarity of the summed inner product between unit rotation vector of pixels on the segment and the unit line direction to the neighboring outline pixel. The summed inner product e is calculated as follows:

$$e = \frac{1}{N}\sum_{i=1}^{N} \vec{r_i} \frac{\vec{d_i}}{|\vec{d_i}|} \quad (2)$$

where $\vec{r}_i$ is the unit rotation vector at ith pixel of the segment. Unit line direction vector $\vec{d_i}/|\vec{d_i}|$is defined as a unit vector that represents the direction of neighboring pixel which is closer to another edge/junction pixel of the segment. The pixel at $i = 1$ in equation (2) is starting point of the segment if e is positive value, and if not so the pixel is regarded as the ending point. The outline segmentation and direction estimation process is shown in Figure 3.

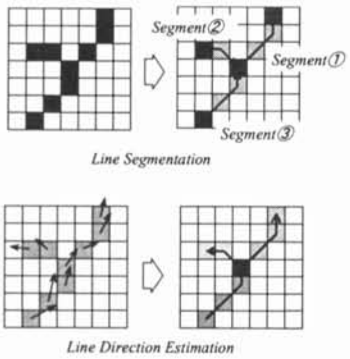

Figure 3. : Illustration of line segmentation and direction estimation process

If it was failed to extract defect area properly, it is necessary to connect segments and estimate the defect area. As the direction is determined for each segment, it is possible to connect the end pixel of a segment with the start pixel of another segment effectively by considering the direction for each segment.

2.4 Area Extraction

Following the segmentation and connection process, first the existence of segment where the start pixel and end pixel is the same is checked. Next closed area search started at start pixel of the longest segment. When the trace reaches at junction, the route which inner product of rotation vector at the point and neighboring is larger is selected. The search is finished when the traced outline goes across other segment. As rotation vectors at surrounding pixels around defect go clockwise, the direction of outline segment also goes around clockwise. By detecting such clockwise segment it is possible to detect the defect area efficiently.

2.5 Multiple Feature Estimation

The extracted area from original image is a candidate of defect, therefore it is necessary to classify the defect pattern into three categories. In this research it is assumed that the existing defect type is whether porosity or crack. In general, these defects have features described below:

- If the outline length is the same, the cross section of porosity is larger than line crack.
- Angular distribution of rotation vector at pixels along the outline for line crack is unisotropic and concentrated in two directions, although the distribution for porosity is relatively isotropic.
- Texture image noise is usually smaller in area size and outline length

Considering these features, the following three measures are introduced for the defect type identification:

S:Area size (cross section) of the defect .
E:Complexity of the defect outline shape .
U:Unflatness of the vector direction profile .

Area size S is the summation of the area surrounded by the extracted outline. Complexity E can be expressed as follows using outline length of defect L:

$$E = \frac{L^2}{S} \quad (3)$$

Unflatness of rotation vector direction profile U is, based on the angular distribution of vectors at outline pixels, also defined as follows:

$$U = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\theta_i - \frac{1}{N}\sum_{i=1}^{N}\theta_i)^2} \quad (4)$$

The parameter θ_i represents the relative angle of the rotation vector at i-th pixel on the outline (N is the number of the pixels which constitutes the outline of the defect) to x-axis of the original image. The U value for crack is larger than for porosity. This measure reflects the intensity profile of original image rather than other outline measure or complexity of the defect outline shape U, because the rotation vectors at pixels on the outline are directly utilized in this calculation.

3 Results

Forty welded test pieces with various types of porosity and crack were prepared in order to investigate the effectiveness of the proposed method. The appearance and size of test piece is shown in Figure 4. In the picture cracks can be seen along the horizontal welding line at the center position. The developed defect identification process was applied to the magnified digital pictures of these test pieces are taken with CCD camera.

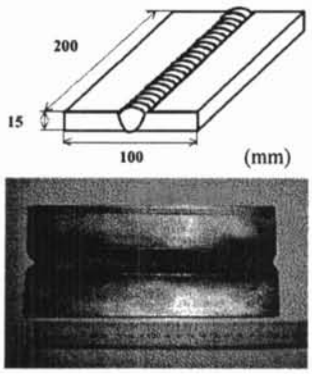

Figure 4. : Appearance and size of test piece

The extracted features for defects in prepared test pieces are plotted in 3D feature space, each axis of which is S, E, U described in section 2.5. The result is shown in Figure 5. The plotted points for defects and noise scatters in different part of the feature space. Porosity plots significantly deviates along S-axis (Defect area size). Plots for crack distribute in the area closer to the U-E plane, that is, Defect area size is relatively smaller than porosity. Image noise plots scatter around the zero point of the space. As a result, it is confirmed that the proposed algorithm is effective for the identification of defect type.

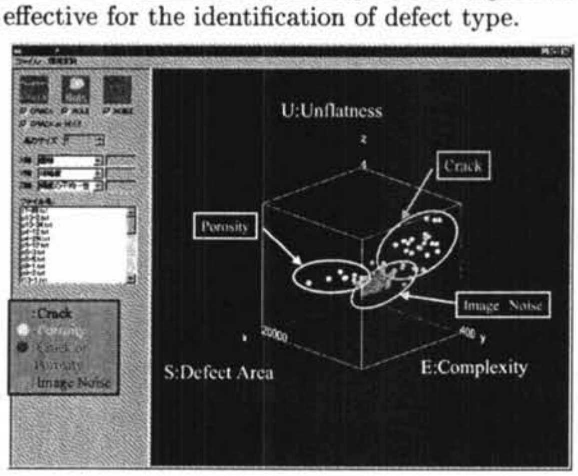

Figure 5. : Feature space plot for the defect type identification

4 Conclusion

A new concept of image processing method based on vector representation for visual inspection test was investigated. The method is based on digital 2D image processing using vector field theory, by regarding intensity of an pixel as scholar potential or one component of vector potential. The superiority of the method is that approximate shape or outline of object in image can be extracted by connecting the rotation vector which is obtained through simple operation only with four neighboring pixels. We have applied the algorithm for extraction and identification of defect types in the welded surface images. Three measures were introduced to distinguish defect types (crack or porosity). First measure is cross section of the defect, second one is complexity and third one is the vector direction profile. The results for acquired images of welded surface with defects were plotted in three-dimensional space, and it was confirmed that the distribution was separated in the space depending on the defect type and they were properly identified. The technique proposed in this paper can be widely applied to various kinds of edge extraction or shape recognition in ambiguous boundary on rough texture.

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