Real-time X-ray Image Processing Based on Information Fusion for Weld Defects Detection

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Abstract

Real-time X-ray imaging and its image processing techniques are often adopted in on-line automatic inspection of defects. Due to high noises, low contrast and moving blur, it is difficult to realize automatic inspection using those image processing techniques. Furthermore, most of the existing automatic inspection systems only use single defect segment method, which leads to the outstanding conflict between false alarm and missed detection. As a result, those systems are hard to be applied in practice. In this paper, the redundancy and complementarity are analyzed in two defect segmentation methods of weld X-ray image, i.e., background subtraction and gray-level wave analysis. Then, the information fusion method of them is proposed. Results show that the false alarm and missed detection are decreased effectively by the information fusion method.

Key words: weld defects automatic inspection, X-ray dynamic imaging, information fusion

1. Introduction

Real-time X-ray dynamic imaging technique is often adopted in on-line inspection of defects in important welding structures, e.g. the manufacturing of the petroleum pipeline. In order to overcome the subjectivity of manual inspection and improve automation and intelligence level, many researches focus on the automatic inspection technique for weld defects based on real-time X-ray image processing. However, the existing automation inspection systems are hard to be applied in practice because of high false alarm and missed detection ratios. One reason for this problem is the poor quality of real-time X-ray images. Besides, most of the existing systems only use single defect detection method, which leads to the outstanding conflict between false alarm and missed detection.

By adopting the information fusion technology [1], many defect detection methods can be integrated comprehensively, i.e., we can take the advantage of each method's credible information and eliminate their redundancy and contradiction. Thus the decision of the system will be more credible. In this paper, the redundancy and complementarity are analyzed in two defect segmentation methods of weld X-ray image, i.e., background subtraction and gray-level wave analysis, and then information fusion based on D-S (Dempster-Shafer) evidence theory is employed to reduce false alarm and missed detection.

1. D-S evidence theory

D-S evidence theory [2] developed the Bayesian Decision Theory. It can efficiently deal with the uncertain problem in different methods. In D-S evidence theory, θ is defined as the frame of discernment, which consists of limited mutually exclusive propositions, and m(x) is the basic probability distributions function, m(x) : $2^{\theta} \rightarrow [0, 1]$, which fulfill the following:

$$m(\phi) = 0 \quad (1)$$

$$\sum_{x \subset \theta} m(x) = 1 \quad (2)$$

The distributions $m_1(x)$ and $m_2(x)$ are obtained by different defect segmentation methods, i.e., A and B. Then, according to the Dempster's evidence combination rule, we can obtain the new distribution

$$m(x) = \frac{\sum_{A \cap B = x} m_1(A) \cdot m_2(B)}{1 - \sum_{A \cap B = \phi} m_1(A) \cdot m_2(B)} \quad (3)$$

For a distribution, the belief function Bel(x) and plausibility function Pls(x) are used to evaluate its uncertainty, where:

$$Bel(\phi) = 0 \quad (4)$$

$$Bel(\theta) = 1 \quad (5)$$

$$Bel(x) = \sum_{xi \subseteq x} m(x_i) \quad (6)$$

$$Pls(x) = 1 - Bel(\tilde{x}) \quad (7)$$

The confidence interval [Bel(x) , Pls(x)] indicates the possible range of the lower and upper probability.

2. Defects segmentation

In the framework of information fusion, the selection of the defect segmentation method is different from the traditional. It doesn't need to take into account the false alarm and the missed detection together, but needs the complementary of these methods, then try to reduce the missed detection as possible in each method and eliminate false alarm by information fuse.

In this paper, the background subtraction method and gray-level wave analysis method are adopted.

2.1 Background subtraction

The background subtraction is one of the usual methods in weld defects segmentation in X-ray Image [3-4]. Firstly, the background image (which does not contain the weld defects) is estimated form the original X-ray weld image. Then, the residual image (which only contains the defects and noises) is obtained through subtracting background image form original one.

In this paper, a low-pass filter is used to estimate the background image. Figure 1 shows the X-ray real-time image of weld. The 3-D distribution of its gray-level is shown in Figure 2(a), and the 3-D distribution of background image gray-level is shown in Figure 2(b). The residual image is obtained after subtraction, and then through binaryzation and morphology filter, the defect segmentation result is shown in Figure 3. There are three false alarms near the weld edge.

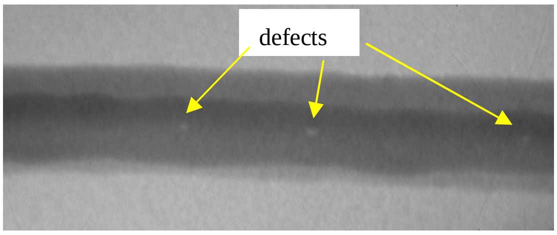
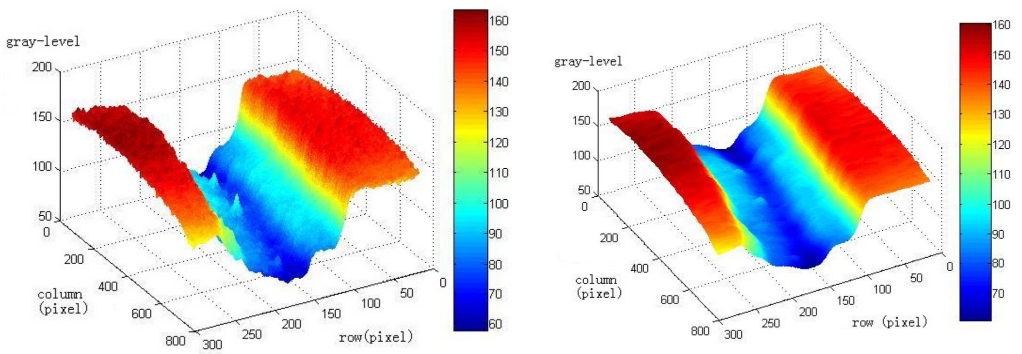


Fig. 1 X-ray real-time image of weld



(a) Original image (b) background image

Fig. 2 3-D distribution of the image's gray-level

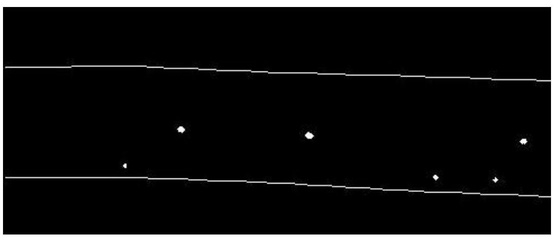


Fig. 3 defect segmentation result of background subtraction

2.2 Gray-level wave analysis

The grey-level wave is analyzed column by column in this method, and defect region is segmented by the wave characteristic. Take a column $y(x)$ which passes through the defect region in Figure 1, and analyze the wave profile as follows (shown in Fig. 4):

(1) Calculate the first order difference $y'(x)$ and second order difference $y''(x)$ of $y(x)$.

(2) Search the point x_0 among weld region in $y'(x)$ which meets $y'(x_0)=0$ and $y''(x_0)<0$, then search zero points x_1 and x_2 separately on each side of the x_0 in $y''(x)$. The interval [x_1, x_2] is the defect region in the current column.

(3) By this means, analyze the image column by column, than the defect segmentation is done and the result is shown in figure 5 (there is a false alarm).

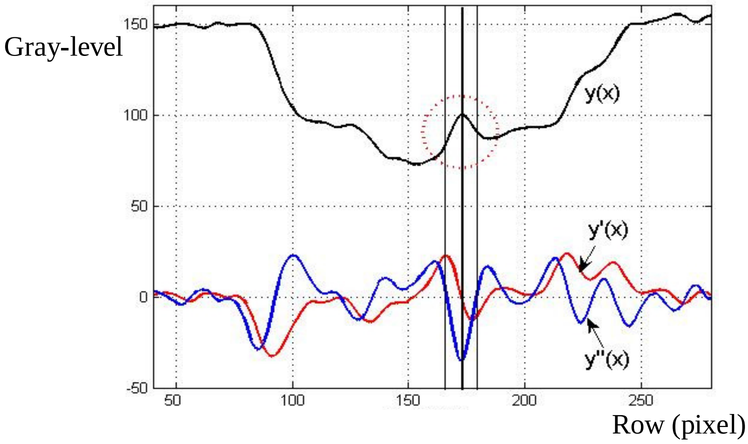


Fig. 4 grey-level wave analysis schematic

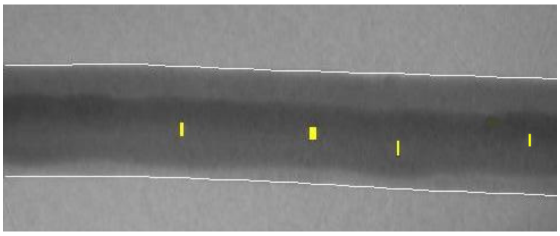


Fig.5 defect segmentation result of gray-level wave analysis

3. Information fusion

The background subtraction method fits for different size of defects and various level of noise. The small defect can be detected effectively. However, the background image is inaccurate around weld edges due to estimating by low pass filter, which results in many false alarms in this region. As to the gray-level wave analysis, it is sensitive to noises instead of weld edges because it is differential operator. And if the image is preprocessed by low pass filter, the small size defect is easy to be missed. Obviously, there has strong complementary between the background subtraction and the gray-level wave analysis, they have the different mechanism of causing false alarms and the region where the false alarms occurred is different. Therefore the missed detection can be reduced as possible in each method by lower the threshold, and then the false alarmed can be eliminate by information fusion.

In the D-S evidence theory, the key to fusion is how to distribute $m(x)$. Assume that $m_T(x)$ is the probability that the "defect" obtained by each detection method before fusion is a real defect, $m_F(x)$ is the probability that the "defect" is false, and $m_{TF}(x)$ is the probability that whether "defect" is true or false is uncertain, i.e., the uncertainty probability.

In the background subtraction method, it's easy to cause false detection in the weld edges, so in the detection result, the "defect" in the weld edges is more uncertain. Assume that D is the width of weld, and d is the smallest distance between the center of "defect" and any weld edge. Then the uncertainty of the "defect" is distributed as follows:

$$m_{TF}(x) = 1 - (2d/D)^3 \quad (8)$$

The real or false probability of the "defect" is distributed by its area. Figure 6 shows the relationship between the area of the "defect" and the false alarm ratio("T" is the threshold used to of the subtract an image to binary image), which is obtained by experiment.

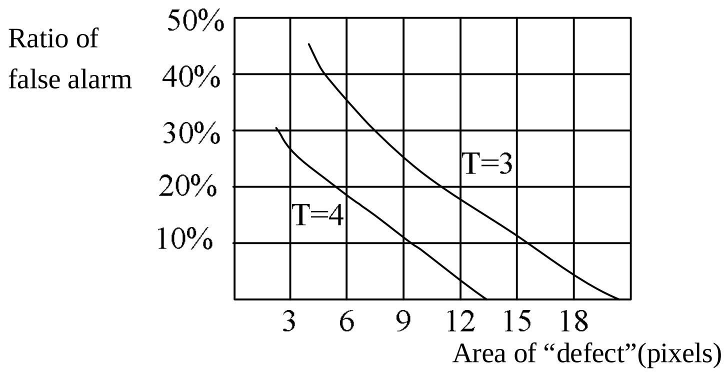


Fig. 6 the relationship between the area of the "defect" and the false alarm ratio

$m_T(x)$ is distributed according to curves in Figure 6. Assume that "k" is the missed detection ratio corresponding to the area of the "defect", then:

$$m_T(x) = (1-k)(1-m_{TF}(x)) \quad (9)$$

$$m_F(x) = k(1-m_{TF}(x)) \quad (10)$$

The distribution method of $m(x)$ in the gray-level wave analysis is similar to that of the background subtraction. Firstly, distribute the "uncertainty" by the length and width ratio of the "defect", and then distribute the real or false probability by the area of the "defect". After distribution, process the information fusion by equation (3), and then set a proper threshold value to judge the authenticity of the "defect". The defect segmentation result after information fusion is shown in Figure 7, which shows that the false alarms are eliminated effectively.

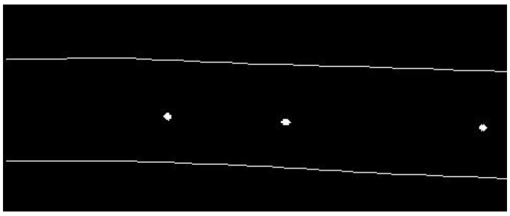


Fig. 7 The defects segmentation result after information fusion

4. Conclusions

In this paper, we aim at the X-ray dynamic image processing of weld defects, and proposed an information fusion method that combines the background subtraction and the gray-level wave based on D-S evidence theory:

(1) The background subtraction and the gray-level wave analyses have strong complementary, we can take advantage of their credible information through information fusion. The missed detection can be reduced as possible in each method by lowering the threshold before fusion, and then the false alarm can be eliminate by information fusion.

(2) The distribution of the basic probability function is the key to fusion. The fusion result shows that the false alarms and missed detections are reduced effectively, which indicates the method we used is correct.

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