

# Development of An Automated Inspection System for Welding Defect Detection

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## Abstract

In industrial radiograph inspection, it is an important step to extract welding region from the radiograph image to avoid processing of complex background. In this paper, a flaw map approach along with contrast adjustment is adopted for enhancing radiograph image processing according to the characteristics of weld radiography. Based on the intensity distribution characteristic of weld, a methodology of automated inspection of welding defects is proposed. The methodology of weld extraction, including cropping the ROI, is described. To demonstrate the effectiveness of the proposed approach, 258 weld radiographic images are examined. The results show that the proposed methodology is effective in extracting welding region and generating a flaw map with the inclusion of potential welding defects.

## 1. Introduction

Welding is one of the major joining processes. Poor quality of welding may lead to the happening of defects such as lack of fusion, lack of penetration, cracks, indication, porosity, drop through, etc. These defects occur at joints, particularly those undergoing high pressure or high temperature, and can cause disaster in critical applications such as failure of components. However, it is not possible to "destroy" the welded joints to expose the defects. Therefore, a number of testing methods has been developed in non-destructive testing (NDT) of welds, namely visual, radiographic, ultrasonic, magnetic, penetrant, electrical, etc [1]. The radiographic testing method is the focus of this paper.

## 2. Image acquisition

In conventional radiographic testing method, X-ray is permitted to penetrate the welded target and the image is essentially a "shadow picture" of the internal structure of the target [2]. Photographic films are exposed and examined by certified NDT inspector using a film illuminator. Nowadays, this visualization method has been improved by the introduction of Computed Radiography (CR) [3] where radiograph images are available immediately after exposure, and can be saved to storage media. Imaging software is used to display the image on a computer monitor. The interpretation is more reliable and easier with image enhancement and

measurement tools provided in the imaging software. However, the process of decision making based on interpretation results is still dependent of human knowledge and experience.

Training and experience are essential for proper interpretation of radiographs. The interpretation is to look for discontinuity in welded structure, such as cracks, and then taking corrective actions based on respective rejection criteria. On the other hand, the quality of radiographic images is a key factor for detecting the welding defects. Therefore, varying the luminances of the film illuminator (in viewing photographic film), or the contrast and brightness of the radiograph image (in CR) is critical to expose the defects from the Region of Interest (ROI). An NDT inspector sometimes may have different opinions with others as the interpretation of weld quality based on film and computed radiography is very subjective. Therefore, an automated inspection system for welding defect detection is developed in this paper.

## 3. Weld extraction

In this study, fuel nozzles in aircraft systems are used for NDT. A nozzle is sent for radiographic testing by using CR technology. The captured CR image is originally saved in the DICOM format. Each weld image contains at least a nozzle with some background information. The intensity of the images falls within a wide range of levels. Therefore, image pre-processing is necessary to identify the location of each nozzle, crop, and enhance the ROI of the nozzle. The ROI is the welding regions along with the heat affected zones.

A series of cropped ROI images at various contrast and brightness levels are saved using the ezDICOM software [4]. ezDICOM is a free software with the ability of reading the DICOM format image with brightness and contrast adjustment, and has an ActiveX component to allow integration into other programming platform.

## 4. Flaw detection

There have been studies on the development of algorithms to extract welds and to identify anomalies in the weld regions. Liao and Ni [5] proposed a weld extraction method based on the observation of the

intensity plot where the plot of a weld looks more like a Gaussian curve than other objects in the image. Then Liao and Li [6] developed a welding flaw detection methodology based on the overall line profile (perpendicular to welding direction). The line profile is plotted by processing the intensity of radiograph images line by line. A good weld has a bell shape with some degree of local variation. A welding defect, such as linear indication results in a disruption, i.e. peak or trough, of the bell shape. However, this methodology works well on welding region with Gaussian curve of characteristics.

In this paper, a procedure for extracting welding defects is proposed. The procedure encompasses a number of steps, namely generating a flaw map, cleansing the flaw map, joining the line segments by region growing, and detecting the "potential defects" or known as flaws in this work.

#### 4.1. Generating the flaw map

The welding region is first automatically cropped for welding defect detection, as shown in Figure 1. The process of cropping involves the identification of welded components in the radiographic image, and follows by the extraction of the welding regions. The extracted welding region is then scanned vertically (line by line) to obtain a set of line profiles that represents the intensity distribution of the image, as shown in Figure 2. In general, the intensity values of the welding defects are lower than the intensity values of their neighboring pixels. Hence, they are represented as troughs. Based on the line profiles generated, the flaw map of the weld region is plotted, as shown in Figure 3.



Fig. 1: The welding region is extracted from the original image

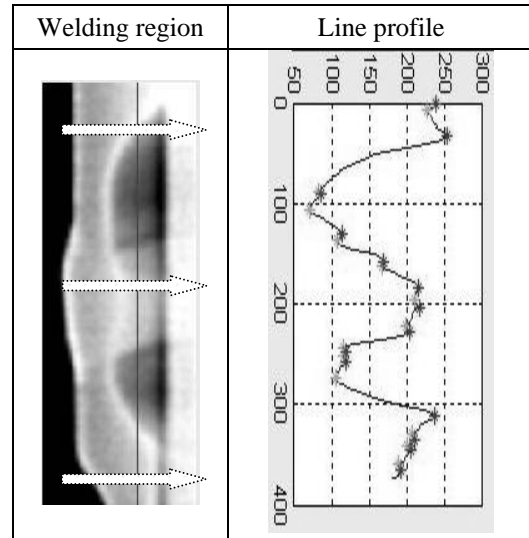


Fig. 2: The welding regions are scanned line by line as shown by the grey vertical lines with their corresponding line profiles plotted. Black and gray crossed-points represent peaks and troughs respectively

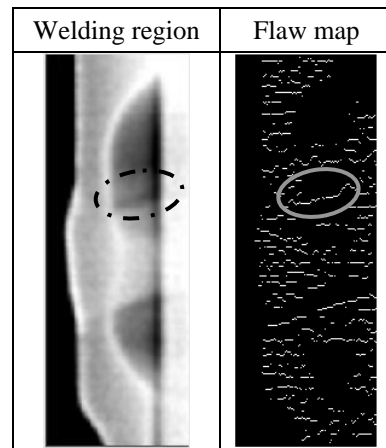


Fig. 3: The flaw map of the welding region with linear indication after being scanned line by line. The circles indicate the location of the defect.

#### 4.2 Cleansing the flaw map

Since the flaw map is plotted based on variation of intensity values of neighboring pixels, noise is plotted in the flaw map together with flaws. Thus, the flaw map needs to be processed and cleansed before the detection of welding defects. A total of 369 line segments are generated in the flaw map (Figure 3), with the defect (i.e., linear indication) in the gray circle. It is, therefore, necessary to remove the non-defective flaws from the flaw map.

The cleansing process of the flaw map is started by identifying the non-welding flaws where the welding defects do not occur. The non-welding flaws are detected using the weld image at a contrast level of 600. Several location points of the unnecessary area are then identified, as shown in Figure 4(a). Based on the points detected, five rectangular regions can be obtained, as

shown in Figure 4(b). Line segments that fall within the five regions are removed.

After investigating the line profiles of all welding defects in the database, it is observed that the intensity values of the welding defects are well below 200. Therefore, the trough points that are above an intensity value of 200 are truncated. A less noisy flaw map that consists of 37 line segments is obtained, as shown in Figure 5(c). This is an improvement of the original flaw map which has 369 line segments, as shown in Figure 5(b).

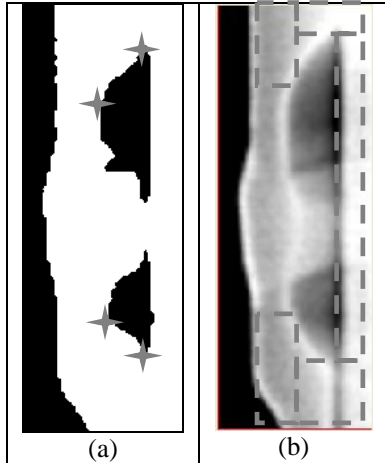


Fig. 4: Removing unwanted area in non-welding regions based on location points

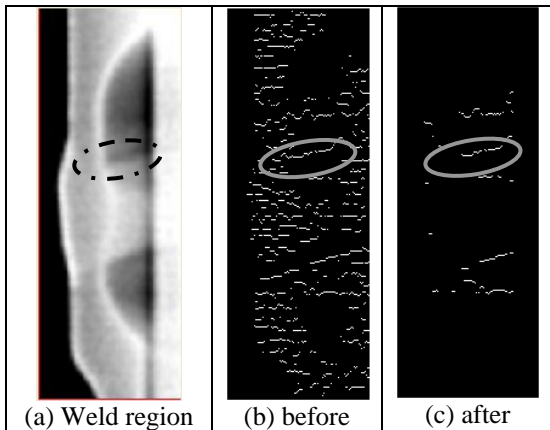


Fig. 5: Comparison of the flaw-maps before and after cleansing

#### 4.3. Joining line segments by region growing

After a more accurate flaw map is obtained (Figure 6(a)), the region growing method [7,8] is used to link all the unconnected flaws. Region growing is one of the simplest approaches to image segmentation; neighboring pixels of similar amplitude are grouped together to form a segmented region. The connectivity of a flaw with another is identified using an eight connected neighborhood mask, as shown in Figure 6(b). The result of region growing produces a total of 24 line segments. Note that the defect, linear indication is successfully segmented, as shown by the gray circle in

Figure 6(c).

#### 4.4. Detecting the defects

To identify the flaw from the line segments, a set of rules that describe the characteristics of welding flaws are generated and used for inference. First, the contrast and brightness values of the welding region (Figure 1) are decreased by 100 and 200, respectively, for four iterations. For each decrement, generation and cleansing of the flaw map and joining of the line segments are implemented to obtain a set of flaw maps, as shown in Figure 7.

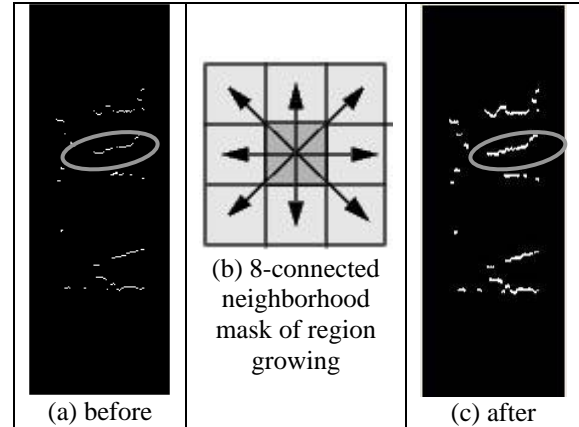


Fig. 6: The operation of region growing. The circle indicates the defect on the flaw map

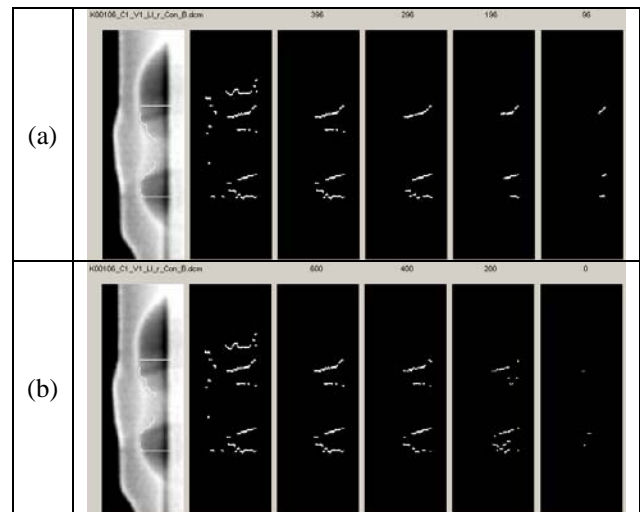


Fig. 7: The contrast and brightness values of the welding region are decreased and a flaw map is generated for each level of decrement  
(a) The flaw-maps of contrast decrement;  
(b) The flaw-maps of brightness decrement

A weighting of 0.25 is given on the line segments that are able to maintain their presence after the contrast and brightness decrements. For example, a line segment which appears on the flaw map for four consecutive decrements of the brightness value receives the highest weighting of 1. The line profile of a non-defective line segment turns to a horizontal line after contrast and brightness decrements, as shown in Figure 8. Non-defective line segments usually have a lower depth

value, as compared with that of actual defect line segments. As a result, they do not appear on the flaw map, as shown in Figure 9, after the contrast and brightness adjustment process.

A threshold value is set to identify the possible defects from the flaw table. For example, a threshold of 0.8 causes line segments 2, 5 and 6 to be detected, as shown in Table 1. To identify the correct defect from other suspected flaw segments, additional features are needed. On the other hand, this approach is applied to test other welding defects, lack of fusion and undercut. The results are shown in Figure 11.

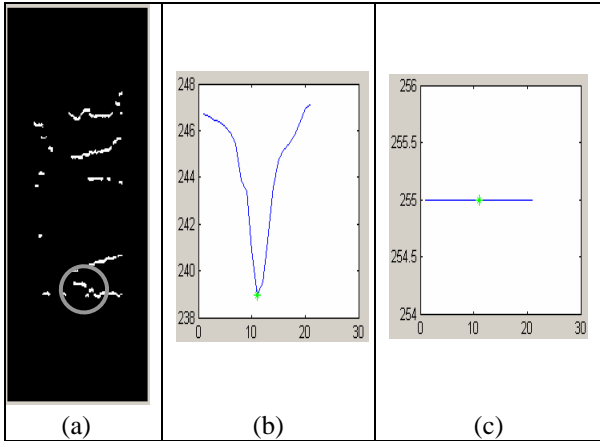


Fig. 8: The effect of brightness decrement on the line profile  
 (a) The line profile of a non-defective line segment (gray circle) is plotted  
 (b) The line profile at a brightness value of 396  
 (c) The line profile at a brightness value of 296 turns into a straight line

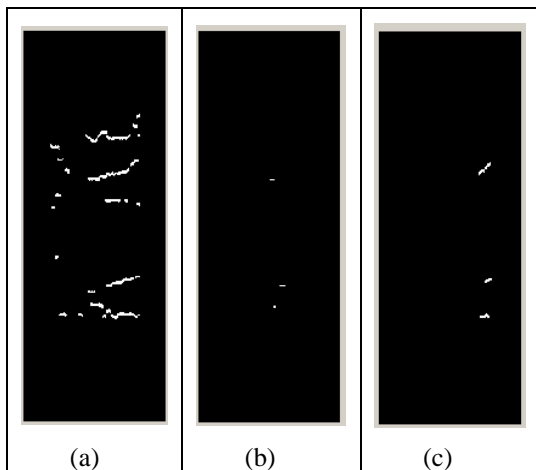


Fig. 9: The effect of contrast and brightness decrement on the flaw map  
 (a) The original flaw map is obtained from the initial contrast and brightness values, i.e. 396 and 600 respectively. The flaw-map generated after (b) the contrast is reduced to 0; and (c) the brightness is reduced to 96.

Table 1. The flaw table is obtained from the sample image presented in Fig. 9

Line segment	Contrast weighting, $W_c$	Brightness weighting, $W_b$	Contrast importance ( $W_c \times 0.3$ )	Brightness importance ( $W_b \times 0.7$ )	Total weighting
1	0.25	0.25	0.075	0.175	0.250
2	1.00	1.00	0.300	0.700	1.000
3	0.50	0.50	0.150	0.350	0.500
4	0.50	0.75	0.150	0.525	0.675
5	1.00	1.00	0.300	0.700	1.000
6	1.00	1.00	0.300	0.700	1.000
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
24	0.25	0.75	0.075	0.525	0.600

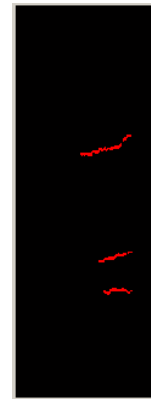


Fig. 10: Three line segments are detected from the contrast and brightness adjustment operations

Defect Type	Welding region with respective flaw map
<i>lack of fusion</i>	
<i>Undercut</i>	

Fig. 11: Same approach applying to the defects of lack of fusion and undercut. Red flaws represent detected line segments.

## 5. Summary

A methodology that produces a flaw map to plot and obtain the welding defect is devised. The flaw map with adjustment of contrast and brightness level is used to segregate the defects from the welding regions. Since the intensity level of defects in the radiographic images are lower than the neighboring regions, therefore, troughs which can be used to characterize the defect are plotted in the flaw map. A set of rules is applied to detect the flaws.

For further work, a comprehensive test on various welding defects is necessary in order to ascertain its usefulness and effectiveness in defect detection and classification. On the other hand, feature extraction can also be investigated to identify the correct defect from the remaining welding flaws.

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