
Incomplete Penetration Type Flaws Detection in Weldments Using Morphological Image Processing Techniques

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Alaknanda Ashok¹

Abstract

It is necessary to detect suspected defect regions in the radiographic weld images to find the flaw and its causative factors. This requires processing of radiographic images by a suitable approach. This paper presents an image processing approach to process incomplete penetration type flaws in radiographic images of the weld specimens considering morphological aspects of the image. In the present approach, radiographic weld image is processed to get the image with good contrast and reduced noise using image enhancement techniques like histogram equalization and noise filtering. This is followed by an effective edge detector such as Canny operator to find the edges of flaws, which are further used to segment the image to fix the boundaries. The boundaries are fixed using morphological image processing approach i.e. dilating few similar boundaries and eroding some irrelevant boundaries decided on the basis of pixel characteristics. The incomplete penetration type flaws are clearly identifiable in the finally processed image, which is obtained by superimposing the segmented image over the original enhanced image.

Keywords

Radiographic Images, Flaw Detection, Edge Detection, Dilation, Erosion

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¹Department of Electrical Engineering, COT, G. B. Pant University of Agriculture and Technology, Pantnagar / WIT, UTU Dehradun, India.

Corresponding author:

Email: alakn@rediff.com



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Introduction

Inspection of welded structure is essential to ensure that the quality of weld must meet the requirements of the design and operation, which assure safety and reliability. Visual human interpretation of radiographic films is a hard and difficult task when a large number of defects are to be detected, counted and calibrated. Quality assessment by human involvement increases the cost of manufactured product. In addition, several experts do not have same opinion on the given film depending upon their previous experience and even the same expert might have a different report at the beginning or end of workday^[1]. To eliminate the slowness and evaluation inconsistency by human experts in meeting the requirements of design and operation with increased the reliability without destroying the product, NDT techniques are used to inspect the welds^[2].

Radiographic testing is the one of the most widely used NDT method for detecting internal welding flaws. It is based on the ability of X-rays to pass through metal and other material, opaque to ordinary light, and produce photographic records by transmission of radiant energy^[3]. The method is based on varying degree of absorption of the penetrating radiation by object on the conventional film radiograph, which produces a latent image of the object being examined. After chemical processing, these latent images are transformed into permanent shadow images of internal and external condition of object. These changes can be recorded such that light patches or lines in the welded region show the lack of material.

The quality of an image is the key factor for detecting weld flaws. The quality of the image depends strongly upon the absorption characteristics of object, which are determined by the thickness of the material, density, material properties of the object. Important factors in radiography also include film type, film density, energy level of source, focus of the film distance, exposure time and developer temperature^[4,5]. The light patches and lines corresponds to different types of discontinuities due to lack of fusion, incomplete penetration, cracks, cavities, slag inclusion, under cuts, and gas cavities or shrinkage cavities. Instead of smooth joint, sometimes, weldments are not properly joined together during the welding process due to different reasons, which produce flaws of different types in weldments. These flaws are seen in the form of gaps, crack or bubbles. Once welds are successfully extracted, now the interest is to identify the defect areas in the weld. Image processing algorithm is applied on these images for such purpose. Image processing plays an important role to determine the flaws and to extract some useful information^[6,7].

Defect Detection in Weld Images

Automatic procedure for defect detection involves mainly four steps: image enhancement, edge identification, segmentation and flaw detection. The steps shown in block diagram are used in this paper for detecting the edges of flaws using morphological methods.

Image enhancement

The radiographic images is converted on 256 gray scale levels and stored in 8-bit TIFF format (Image digitization) using a suitable scanner. The quality of these radiographic images is improved by employing suitable techniques. The image quality improvement involves noise removal and contrast adjustment. Noise removal is basically a filtering process used for suppressing irrelevant information in the image. It corrects degradation in an image. The contrast adjustment is done using histogram stretching. Histogram equalization follows thereafter for equal distribution of brightness levels over the whole brightness scale.

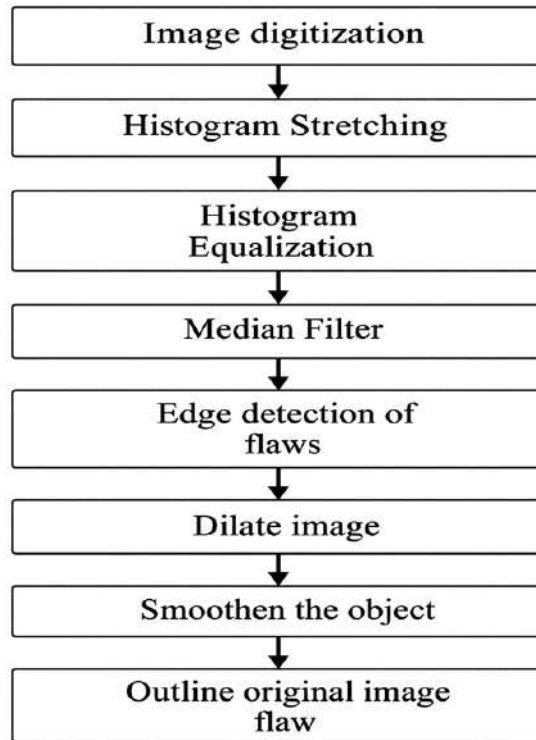


Figure 1. Steps used for image processing

Median filter is used to remove unwanted noise from the image because median smoothing eliminates impulse noise quite well without blurring the edges.

The original X-Ray image having incomplete penetration, the image after histogram equalization and the image after median filtering are shown in Fig. 2, Fig. 3 and Fig. 4 respectively. These figures are annexed at the end of paper.

Edge Identification

After image quality improvement, edges are determined in the welding zone. The edges are formed where there are abrupt changes in the intensity of the pixels. There are different types of edge detectors, which can be used for detecting the edges having different characteristics^[8,9]. The Canny edge detector^[10] is a very important method for local preprocessing to locate changes in intensity function, having good signal to noise ratio. In Canny operator, the main criteria are the detection of all important edges and the distance between actual and located position of edge after using edge detector, should be minimal and the minimum number of multiple response to single edge. In order to reduce noise in canny operator Equation (1) and Equation (2) are used. Image $f(x)$ is smoothed by convolution with a Gaussian of

scale σ , where σ is standard deviation.

$$G(x, \sigma) = e^{-\frac{x^2}{2\sigma^2}} \quad (1)$$

$$F(x, \sigma) = f(x) * G(x, \sigma) \quad (2)$$

$F(x, \sigma)$ represents a surface on (x, σ) plane. The direction n of local edge in Canny-operator is estimated for each pixel in the image by using Equation (3). Edge point is a point having maximum strength in the direction of gradient.

$$n = \frac{\nabla(G * f)}{|\nabla(G * f)|} \quad (3)$$

Where, G is 2D Gaussian function and f is an image function. With the help of Equation (4), the location of edge is obtained, which is also known as non-maximal suppression because location is tracked along the top of obtained ridges. All pixels that are not actually on the ridge top are set to zero. This procedure of tracking the location of edges has been set to obtain a thin line at the output.

$$\frac{\partial^2}{\partial n^2} G * f = 0 \quad (4)$$

In Canny operator thresholding of edges in image with hysteresis is done in next step to eliminate spurious responses. For thresholding the magnitude of edge is computed by using Equation (5).

$$|G_n * f| = |\nabla(G * f)| \quad (5)$$

Two thresholds T_1 and T_2 , with $T_1 < T_2$ are used to threshold ridge pixels. Ridges having value greater than T_2 are said to be 'strong' and the other ridge values are considered as weak.

The obtained image shows edges of flaws in the form of high contrast lines. High contrast lines do not delineate the outline of the object of interest very well. As compared to the original image gaps can be seen in the lines surrounding the object in the gradient mask image. These gaps can be eliminated with the help of morphological techniques. The binary gradient image of filtered image is shown in Fig. 5.

Segmentation

Using a suitable threshold value edge profiles are obtained in binary format i.e. one for edge and zero for no edge. The image at this stage is in form of contours. Contour has discontinuities due to crack edges. To obtain closed contour, morphological image processing is performed on the image.

Morphological processing involves erosion and dilation of edges on the basis of edge features.

The image is first dilated and then eroding is performed on the image to get closed contour^[11,12]. In dilation by using appropriate structuring elements, high contrast lines having gaps in binary gradient mask image disappear. These linear gaps disappear if the Canny image is dilated using linear structuring elements. Dilation is an operation that 'grows' or 'thickens' objects in binary images. Mathematically, dilation of A by B denoted as $A \oplus B$, is defined as Equation (6)

$$A \oplus B = \{z / (B)_z \cap A \neq \Phi\} \quad (6)$$

where Φ is empty set, B is structuring element and A is object to be dilated.

Dilation is used to fill small holes and narrow gulfs in objects. The binary gradient mask image is dilated using the vertical structuring element followed by the horizontal structuring element. The dilated gradient mask of the binary image is shown in Fig. 6.

After dilation smoothening of the object is done in order to make the segmented object look natural. The object is smoothened by combining dilation with erosion to preserve the original size. Erosion of A by B is the set of all points z such that B, translated by z, is contained in A and represented by Equation (7)

$$A \ominus B = \{z / (B)_z \subseteq A\} \quad (7)$$

The object is smoothened by eroding the image twice using appropriate structuring element (e.g. line, disk or diamond). When the dilation is followed by erosion it is known as morphological closing, which is mathematically denoted by Equation (8)

$$A \bullet B = (A \oplus B) \ominus B \quad (8)$$

The segmented image is shown in Fig. 7.

After dilation and erosion, the image in the form of detected images is superimposed on the original image. The segmented image superimposed on original image is shown in Fig. 8.

Feature Extraction

The final image, which is obtained after superimposition of segmented image on original image, is analyzed for its characteristic features. A visual approach is used here to characterize the defects. The defects cases analyzed here are of incomplete penetration type, which have been taken from the standard database.

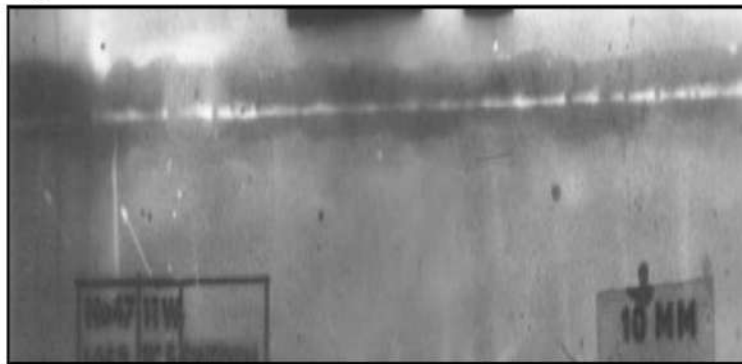
Results and Discussions

The radiographic images, considered here, have been taken from standard database. The cases considered have been of incomplete penetration type. The various stages of processing for one case has been shown here and for few cases only original and final images are produced. Fig. 2 shows an X-ray image of incomplete penetration and transverse cracks type flaws. Fig. 3 shows the results of histogram equalization. Here, contrast adjustment is clearly observed. Fig. 4 presents the result of median filtering. The smoothness in image is obvious in the image after removal of noise. The edge profiles as obtained in the form of contour are shown in Fig. 5.

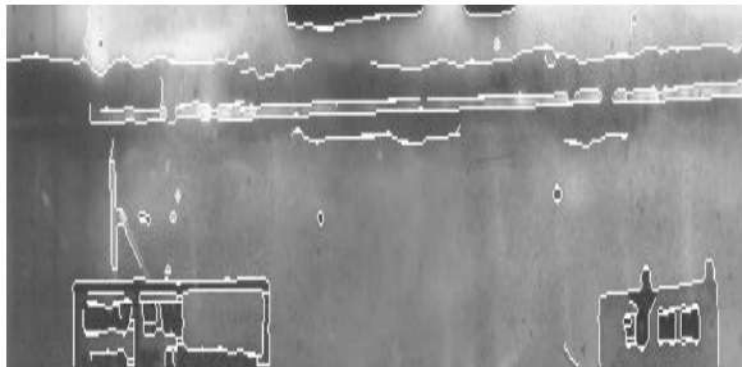
This is binary gradient image of enhanced image, which is obtained after the application of Canny operator on Figure 4. The dilated gradient mask of the binary image is shown in Fig. 6. The superimposition of segmented image (fig. 7) on original image is shown in Fig. 8. In this image, incomplete penetration type of weld defect is seen.

Fig. 9(a) shows an X-ray image of incomplete penetration of another case. It is steel material having thickness ~10mm. metal arc welding process is used for V-shape Butt type welding at down hand position. Radiographic image is taken at 150KV without using screen. The Fig. 9(b) in this case is the

segmented image after all the steps of processing. Similarly, Figs. 10(a)-16(a) show the different cases of weld images and Figs. 10(b)-16(b) show their corresponding segmented for feature extraction.

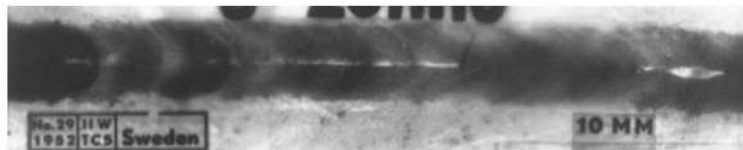


(a)

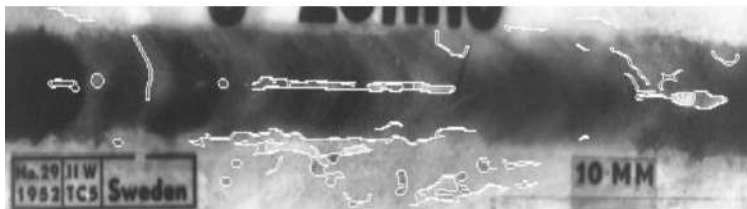


(b)

Figure 2. (a) is the X-ray image of incomplete penetration and (b) Segmented image superimposed on original image. It is steel material having thickness $\sim 10\text{mm}$. metal arc welding process is used for V-shape Butt type welding at down hand position. Radiographic image is taken at 150KV without using screen.



(a)



(b)

Figure 3. (a) is the X-ray image of incomplete penetration and (b) Segmented image superimposed on original image. The image is for the steel material having thickness $\sim 10\text{mm}$. metal arc welding process is used for V-shape Butt type welding at down hand position. Radiographic image is taken at 150KV without using screen.



(a)



(b)

Figure 4. X-ray image of incomplete penetration is shown in (a). (b) Superimposition of segmented image on original image. It is steel material having thickness $\sim 11\text{-}30\text{mm}$., metal arc welding process is used for V-shape Butt type welding at down hand position. Radiographic image is taken at 150KV with H.D. screen Radiographic method.

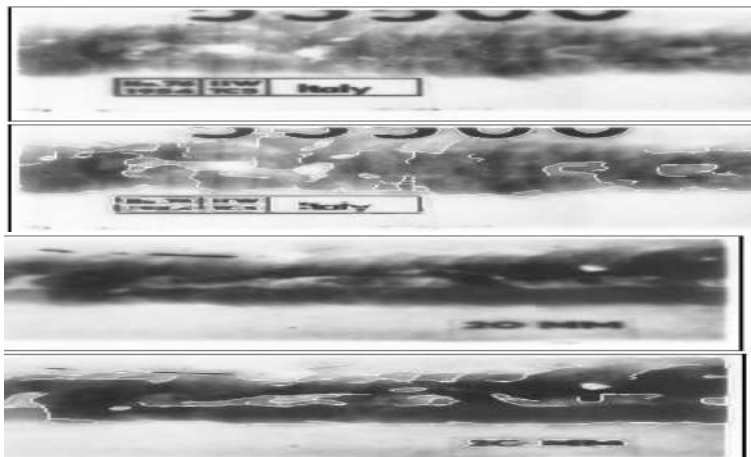


(a)



(b)

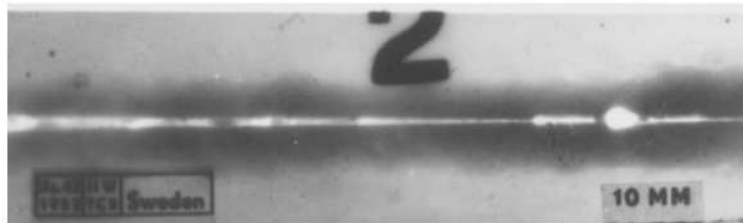
Figure 5. (a) X-ray image of incomplete penetration is shown. (b) Superimposition of segmented image on original image. It is steel material having thickness ~ 11 -30mm., metal arc welding process is used for Y-shape Butt type welding at down hand position. Radiographic image is taken at 150KV with Lead screen Radiographic method.



(a)

(b)

Figure 6. (a) X-ray image of incomplete penetration is shown. (b) Superimposition of segmented image on original image. It is steel material having thickness ~ 11 -30mm. metal arc welding process is used for X-shape Butt type welding at Vertical weld position. Radiographic image is taken at 150KV with H.D. screen Radiographic method.



(a)

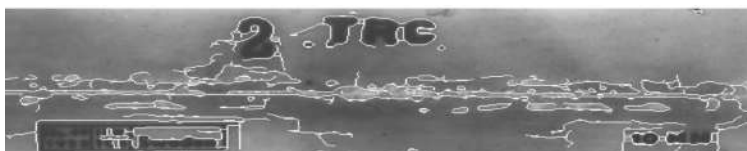


(b)

Figure 7. (a) X-ray image of incomplete penetration flaw is shown. (b) Superimposition of segmented image on original image. It is steel material having thickness $\sim 10\text{mm}$., metal arc welding process is used for V-shape Butt type welding at down hand position. Radiographic image is taken at 150KV without screen.

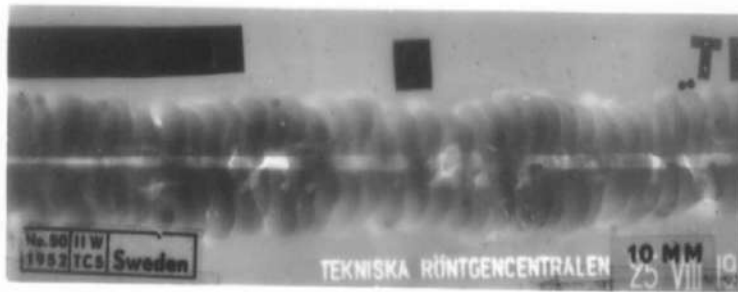


(a)

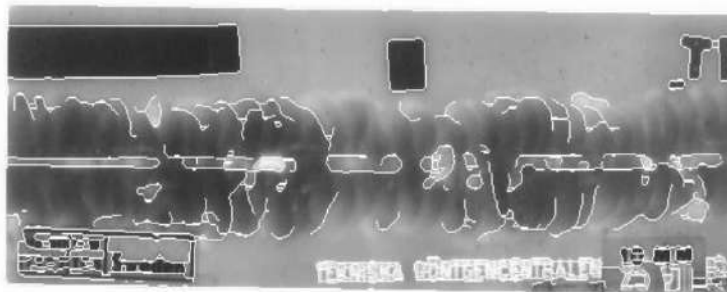


(b)

Figure 8. (a) X-ray image of incomplete penetration, slag line and worm holes type of flaws is shown. (b) Superimposition of segmented image on original image. It is steel material having thickness $\sim 10\text{mm}$., metal arc welding process is used for V-shape Butt type welding at down hand position. Radiographic image is taken at 150KV.



(a)



(b)

Figure 9. (a) X-ray image with incomplete penetration, under cut, slag inclusion type of flaws is shown. (b) Superimposition of segmented image on original image. It is steel shape Butt type welding at Vertical weld position. Radiographic image is taken at 150KV without screen. Material having thickness $\sim 10\text{mm.}$, metal arc welding process is used for V-shape Butt type welding at Vertical weld position. Radiographic image is taken at 150KV without screen.

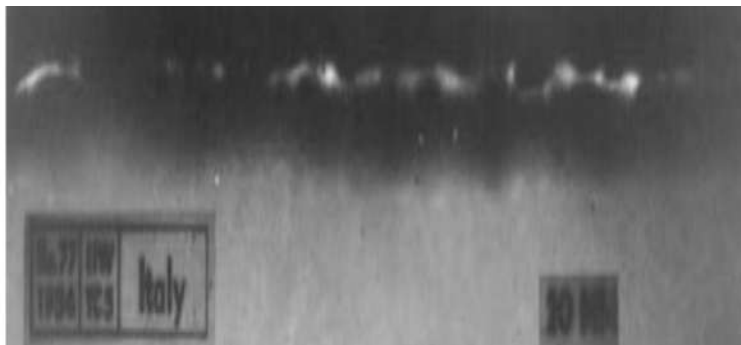


Figure 10. Original X-Ray image having incomplete penetration

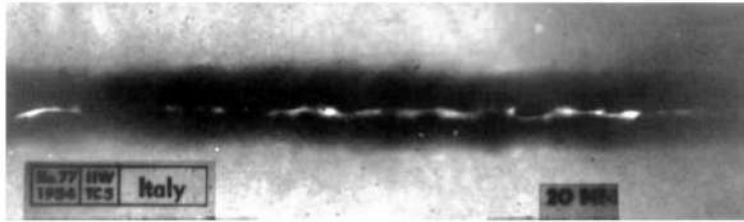


Figure 11. Image after histogram equalization

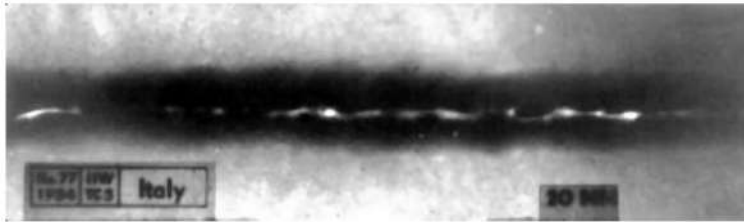


Figure 12. Image after median filtering



Figure 13. Binary gradient image of filtered image

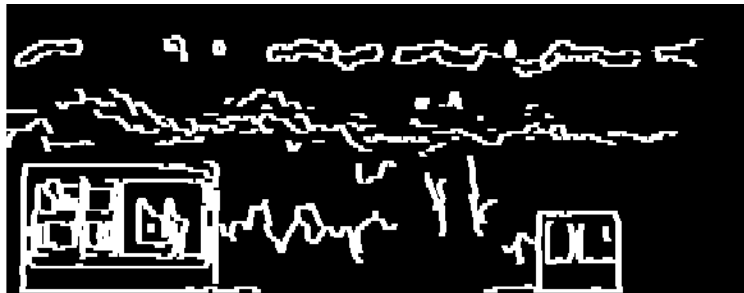


Figure 14. Dilated gradient mask of the binary image

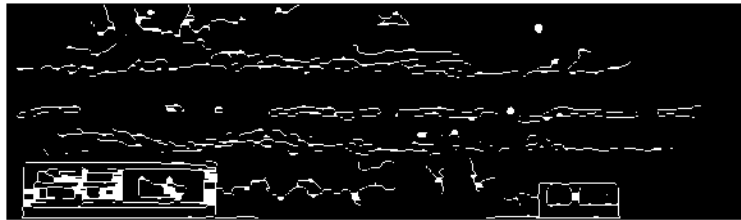


Figure 15. Segmented image

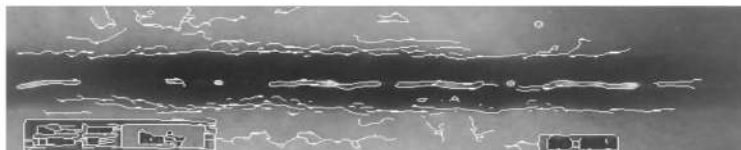


Figure 16. Segmented image superimposed on original image

Conclusions

It is very useful in industries to find out the flaws during the welding operations. The image processing technique can be used to find out the position of the flaw in weldment, which will be further helpful in finding out the type and the cause due to which flaws are produced. This can be useful in reducing the flaws by controlling the relevant weld parameters. This suggested algorithm has been tested on different industrial radiographic images depicting the various types of welding defects choosing appropriate threshold value for Canny operator to find the edges. Different contours of weld defects can be extracted and can be further tracked by using morphological functions to indicate the flaws in an image.

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