Image Enhancement Process on Digital Radiographic Image with Weld Discontinuities

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ABSTRACT

Non Destructive test (NDT) is the most popular and commonly used method to evaluate the condition of the test target area without damaging it properties. In welding industry, the purpose of NDT is to inspect and evaluate the existing of discontinuity in the joining part that cannot be seen by naked eyes. Due to the problem poor quality of radiographc image during data acquisition, this research aims to develop image enhancement process in order to improve and analyze the quality of the radiographic image. A low quality of image is enhanced using image processing methods for better image visualization. The methods used are noise removal and contrast adjustment using circular average filter and logarithmic intensity contrast respectively. For continuity detection, edge detection and thresholding with morphological structuring element are applied. The performance and accuracy of the segmented image is determined using Receiver Operating Characteristics (ROC). Results indicate that the quality of the image is improved and the welding discontinuity is successfully extracted. The implementation reduces the time consuming and cost spending in NDT process besides helps the radiographer in inspecting and evaluating a discontinuity accurately.

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Introduction

Industrial Radiography has been used widely for weld discontinuity detection. In Non Destructive Test (NDT), industrial radiography used x-ray and detected image are directly shown on computer. It is an effective method and provides faster way of image detection due to the availability of direct image monitoring. It is also easy to store the image in the computer storage. Basically, there are two types of industrial radiography imaging, which are conventional imaging and digital imaging. Conventional imaging is a technique that uses film indicator to display image. It used intra-oral radiographic film. The film acts as radiation detector and image display. Indirect action receptors and extra-oral films are used to record the image [1]. The film is sensitive to light photons which emitted by adjacent intensifying screens. Digital imaging also known as digital radiography (DR) is a technique that creates computer-generates image that provides an accurate representation of the targeted image.

Digital radiography continues to evolve rapidly as the detector technolog. DR is a proven and reliable NDT method. One of the main industries of the application of radiography is weld inspection. In detecting of weld discontinuity, the digital radiography plays a big role. The weld discontinuity becomes easier to detect and more relevant among the welding inspector using DR. Welding inspector or radiographer could interpret the image by DR using the exits reference of the discontinuities image. Industrial radiography is a method that uses penetrating and ionizing inspection radiation to detect the internal discontinuity in the welded joint like porosity, crack, lack of penetration and others. With DR, image is easy to interpret and apply with image processing technique in order to increasing the image quality. Digital image processing is used in DR to covers set of processes for improvement and extraction of qualitative information in digital images according to user needs.

The advantages of DR are volumetric inspection, that able to detect surface and subsurface flaws, permanents records and good quality control method [2]. In contrast, the disadvantage and limitations of the method are the equipment used can be bulky and heavy, radiation hazard, requirement of control access in the testing area, expensive equipment, unable to detect critical flaws, result required from experienced inspector and image is not suitable for certain configurations of contrast.

The presences of minor discontinuities have little effect on strength or toughness impact but ductility could reduced. The reduction in ductility is an attributed to the formation of low ductility regions or “haloes” (fisheyes) surrounding the discontinuities. The haloes are easily detected on the fracture surfaces of the tensile and bend test specimens [3]. The haloes are caused by the interaction of strain and the hydrogen present in the cavities formed by associated with weld discontinuities

In the real welding industries, they still apply the conventional way, film radiography instead of DR due to the cost of converting the previous technology. By using DR, an image is can be immediately view on computer and user able enhances the image using appropriate processing techniques. Image processing is a process that interprets and manipulates the original image using some techniques to improve its quality. The process includes image enhancement and noise removal. Image quality can be defined as the specification or image level whether it is a high quality image or not. In other word, it is an image characteristic that measures the degradation of the perceived image. Examples of image quality factors that evaluate the quality of image are Peak To Signal Noise Ratio (PSNR), Mean Square Error (MSE), Modulating Transfer Function (MTF), Subjective Quality Factor (SQF), Signal To Noise Ratio (SNR), unsharpness and contrast sensitivity [4].

The poor quality of radiography image is due to the physical nature of radiograph as well as the small size of defect and poor orientation relatively to the size and thickness to evaluate the image [5]. In manual inspection, normally several common problems could occur such as difficult to measure the internal defect parameter, unable to enhance noisy image and time consuming in defining internal discontinuities. Besides that, manual inspection require skillful inspector that should be knowledgeable and gain a lot of experiences in welding sectors to make sure the result more reliable. The visualization become more difficult when the image is noisy, blurred, improperly bright and out of focus [6].

The objectives of the research are to improve the quality of radiographic image using noise removal and contrast enhancement techniques and extract the welding discontinuities (porosity and slag inclusion) from radiographic images using edge detection and thresholding techniques. In addition, the quality of the processed radiographic image is also been evaluated.

Literature Review

The discontinuities on radiographic image are detected by viewing the weld shape and variations in the density and contrast of the processed image. The most common welding defect of the weldment are porosity, inclusion, cold lap, lack of penetration, concavity, under cut and mismatch [7]. Figure 1 shows a digital radiographic image with the location of defect in the root on weldment.

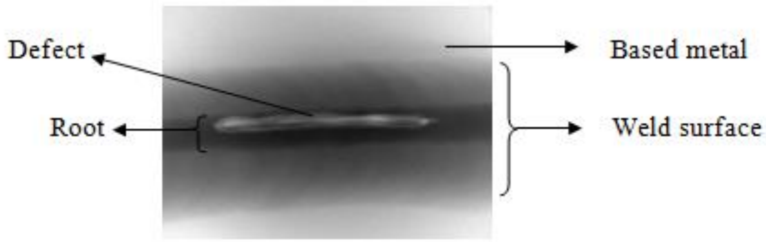


Figure 1: Flawed Specimen Distribution.

According to Khan [2], weld form a shadow image on digital image that is radiograph the area of low absorption (defect such as slag and porosity) appear as dark areas on the developed film while areas of high absorption (dense inclusion) appear as light areas on the developed image as shown in Figure 2.

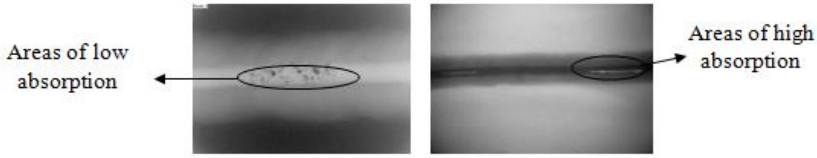


Figure 2: Area of Absorption.

Image processing is a technique that modifies an image to improve its quality, contrast and density accordingly to the image requirement. According to Rapp [8], image processing modify image by any enhancement or restoration element, extract information such as analysis and recognition and change their structure

Image enhancement is a process to emphasize and sharpen image feature for display and analysis. It is for image looks better with good visual quality and good image boundary detection.

Hasinoff and Kautz [9], Foffani, Bianchi and Cincotti [10] proposed to used laplacian to remove blurring effect of image. Terrien, Marque, Steingrimsdottir and Karlsson [11] stated that the laplacian filtering removes the signal obtained by the average signal of surrounding channels as opposed to adaptive filters that remove only the parts of the original signal that correlate to the reference signal

Results from [12] indicate that average filter outperformed that other type of filters in removing Gaussian noise of Salt and Pepper noise. The median filter produces the highest quality of filtered image on all levels of noise density.

Since radiographic image usually poor in contrast, its contrast adjustment can be the main element to be manipulated. In the original radiographic images, the distribution of gray level is highly skewed towards the darker side. Mokhtar, Harun, Mashor and et al. [13] had compared four type of contrast stretching which are Local and Global Contrast Stretching which locally adjust each picture element value to improve the visualization of structure in both darkest and lightest portion, Partial Contrast that increase the contrast level and brightness, Dark Contrast Stretching and Bright Contrast Stretching that auto scaling method which is a common linear mapping function to enhance the brightness and contrast level of an image.

Image segmentation is a useful tool in many reality including industry, health care, astronomy, and various other fields. The idea of Segmentation by simply looking at an image, one can tell the regions that contained in image. Visually it is very easy to determine image region of interest and not target region. Naccereddine, Zelmat, Belaifa and Tridi [5] proposed Otsu thresholding for bimodal image and Niblack tresholding for the detection region after contrast enhancement remains drowned in the background. Mahmoudi and Regragui [14] implemented Otsu's and Sauvola's thresholding with nxn window size on images to highlight the defect. The integration of the technique significantly inproved the computing time. Yahia, Belhadj, Breg and Zghal [15] proposed thresholding by Maximizing Interclass Variance (MIV) in radiography images before the contour detection process using Sobel and Canny. Essentially, the Multilayer Perceptron (MPC) is used that gives better contour detection.

In order to obtain the quality experimentally, image quality indicator (IQI) is used to control the quality of the image. The purpose of an IQI is to indicate the overall sensitivity of the technique and as a measurement of how well the radiograph reveals discontinuities. The sharpness of a photographic imaging system is characterized by a parameter called MTF, that also known as spatial frequency response. The MTF is a fundamental measure of imaging system sharpness.

The PSNR is a parameter for the ratio between the maximum possible powers of a signal with the power of corrupting noise that affects the fidelity of its representation. PSNR is usually expressed in terms of the logarithmic decibel scale due to many signals that have a very wide dynamic range. A higher PSNR normally indicates the reconstruction of higher quality image. Receiver Operation Characteristic (ROC) analysis is a method that able to measure the effectivenss of the methodology [16]. It can be measured with ROC curve that represented by sensitivity (s_n) versus '1-specificity' ($1-s_p$) [17].

Methodology

There are 5 main steps involved in the research methodology. The steps consists of data acquisition, image enhancement, quality evaluation, image segmentation and accuracy calculation. The overall flowchart represents the methodology is presented in Figure 3.

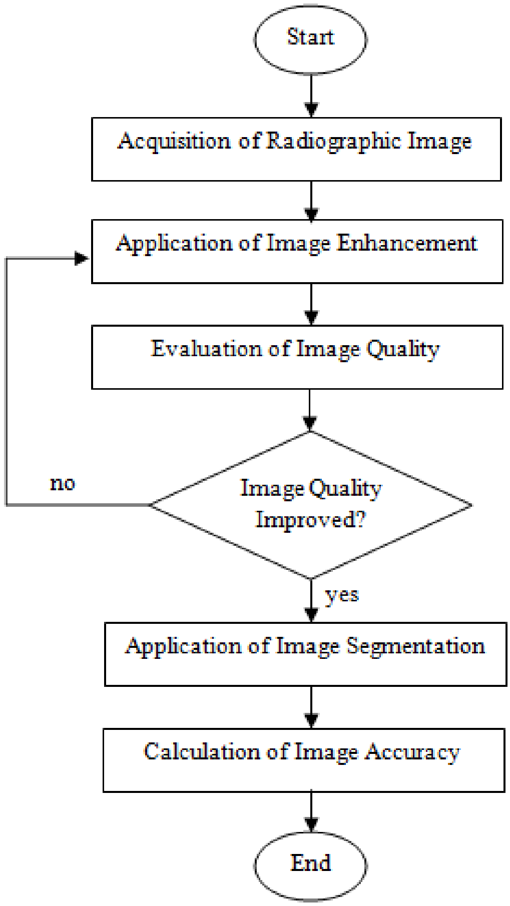


Figure 3: Flowchart of Methodology.

The first step in methodology is radiographic image acquisition. Several samples of welded specimens are captured using phoenix µ-Focused Digital Radiographic Machine: NDT Analyzer as shown in Figure 4. This machine apply direct DR process in which the captured radiographic images of weld are directly stored in a computer. All the images are stored in TIFF format with the size of 1600x1128 pixels.

Figure 4: NDT Analyzer Machine.

Three samples of flawed specimen have been used for image acquisition. The data collected using different setting of parameters that are exposure time, current, voltage, Focal to Object Distance (FOD) and Focal to Detector Distance (FDD) as shown in Table 1.

Table 1: Parameter Setting for Image Acquisition

Specimen	Discontinuity	Exposure Time (µs)	FOD and FDD (mm)
1 (Pl11276)	Porosity Voltage: 180kV Current: 130mA	200	FDD : 0.8390 FOD : 0.5460
2 (Pl11365)	Slag/LOF Voltage: 150kV Current:150mA	200	FDD : 0.7760 FOD : 0.5400
3 (Pl11364)	Porosity Voltage: 170kV Current: 180mA	200	FDD : 0.8950 FOD : 0.4540

Figure 5 illustrates the FDD, FOD and the flawed specimen arrangement before the acquisition process. The FDD presents the distance between the image intensifier with the source (x-ray tube). While the FOD presents the distance between the object (specimen) with the source (x-ray tube).

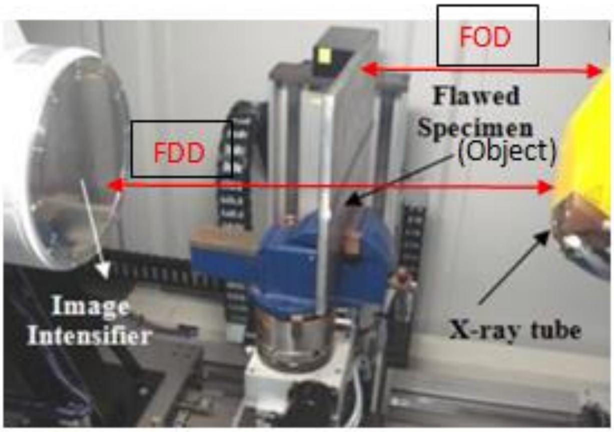


Figure 5: Radiography Source, Detector and Flawed Specimen Arrangement.

Figure 6 shows a sample of flawed specimen that is used to acquire image data for experimental purposes. In this research, the specimen with porosity and slag inclusion are captured.

Figure 6: Sample of Welded Flawed Specimen.

In order to define the quality the radiographic image, the flawed specimen is set with tungsten, single wire, duplex wire and label. The set up is shown in Figure 7.

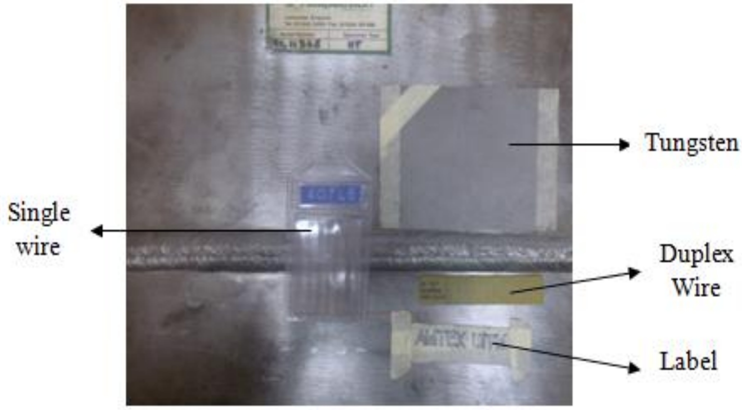


Figure 7: Arrangement on the Flawed Specimen.

Figure 8 presents an example of radiographic image that is captured using phoenix µ-Focused Digital Radiographic Machine that contains porosity defect.

Figure 8: Radiographic Image of the Flawed Specimen.

Image processing is implemented in order to improve the image quality. This process involved noise removal using Circular Average filter and Contrast enhancement using Logarithmic intensity contrast to enhance radiographic images. Circular Average filter is used to reduce the image noise and Logarithmic intensity contrast is used to improve the image contrast respectively.

Figure 9 shows the intensity distribution using image histogram after implementing noise removal technique. The pixel values are evenly distributed over the entire image intesity range and essentially increase the image contrast.

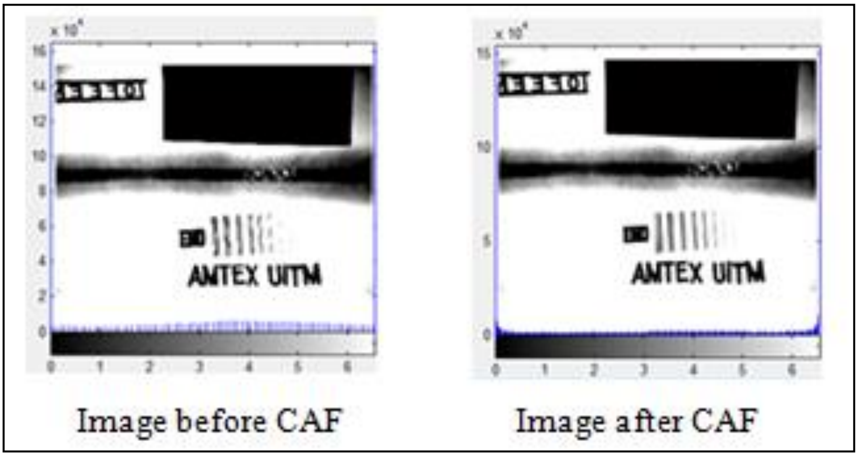


Figure 9: Image and Its Histogram Using Circular Average Filter (CAF).

Figure 10 shows the image after Logarithm transformations. Both implemented techniques purposely aim to remove the noise and enhance the contrast quality of the image.

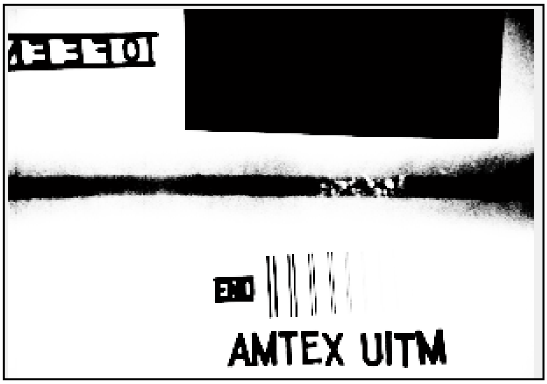


Figure 10: Processed Image after Logarithm transformation.

In segmenting the discontinuities, area of region of interest (ROI) is selected in the image. The area contains weld discontinuity is selected in order to reduce the time processing. The segmentation technique based on edge detection and thresholding are then implemented on the ROI. Sobel is used as edge detection process. Morphological structuring elements (strel) also apply in the thresholding process. Figure 11 shows image after Thresholding technique with threshold value determined by user.

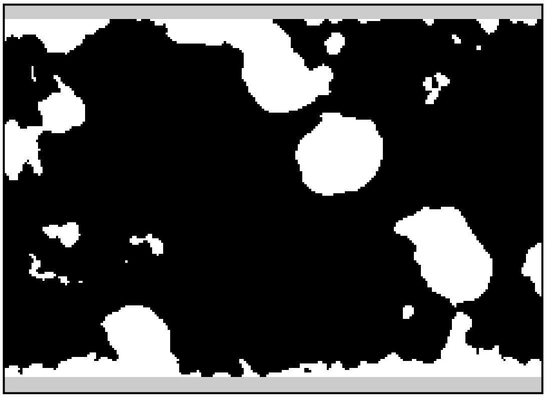


Figure 11: Image after Image Thresholding.

In order to remove unnecessary area in the image border, all the white regions that connected to border are deleted. Figure 12 shows the results of image after the process.

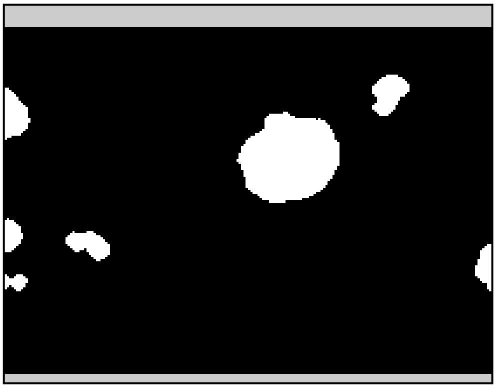


Figure 12: Image after Clear Border.

In the last process, the boundary of discontinuity that marked with white region are detected and extracted using Sobel edge detection. Figure 13 shows the detected boundary obtained in the processed image.

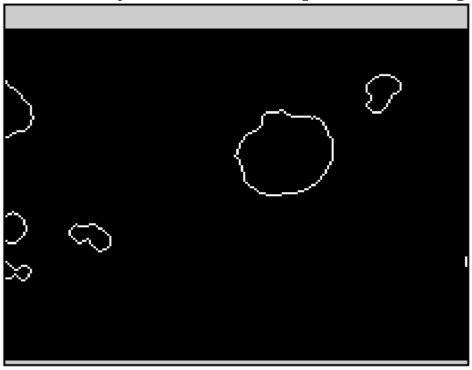


Figure 13: Image after Edge Detection.

The quality performance between processed and original images is evaluated using *PSNR* and *NAE*. The *PSNR* is defined using equation (1).

$$PSNR = 20\log_{10}\frac{MAX_I^2}{\sqrt{MSE}} \tag{1}$$

where the *MSE* is defined as:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[f(i,j) - f'(i,j)\right]^2$$

The *NAE* is calculated using equation (2).

$$NAE = \frac{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[f(i,j).f'(i,j)\right]}{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1} f(i,j)} \tag{2}$$

where:

mn = image dimension in row,*m* and column,*n*.
f(i,j) = the pixel value at (*i*, *j*) of the original image.
f'(i,j) = the pixel value at (*i*, *j*) of the processed image.
MAX_I = maximum value of image pixel value.

NAE is computed using equation (2) is a measurement on the decompressed image from the original image with the value of zero being the perfect fit. A large value of *NAE* and small value of *PSNR* indicates poor quality of image [18].

In order to evaluate the accuracy after the segmentation technique, the performance of the segmented image is determined using ROC. The ROC determined the sensitivity and the specificity of the technique.
Sensitivity is defined as:

$$S_n = \frac{TP}{TP + FN} \tag{3}$$

1-specificity is defined as:

$$1 - S_p = \frac{FP}{TN + FP} \tag{4}$$

where;

TP represents correctly defined as discontinuity.
TN represents incorrectly defined as non discontinuity.
FP represents correctly defined as non discontinuity.
FN represents incorrectly defined as discontinuity.

Result and Discussion

The original image and processed image are evaluated by measuring the value of PSNR and NAE. Table 2 shows the results of 4 samples of images before and after enhancement with the value of PSNR, MSE and NAE. Large value of MSE and NAE indicate poor image quality of image.

In can be observed that the processed image shows a better quality of image with highlighted weld discontinuities. This results improve the accuracy of the discontinuities detection process later.

After the segmentation technique has been implemented, segmented region has successfully follows the requirement to detect the discontinuities. Table 3 demonstrates several results on segmentation of weld discintinuities.

The accuracy of the segmentation technique is evaluated using ROC based on 22 radiographic images. The total number of TP, TN, FP and FN is illustrated in Table 4.

Table 5 shows the calculated values of sensitivity and specificity based on equation (3) and (4).

The graph of sensitivity against 1-specificity as shown in Figure 14 is plotted to determine the accuracy performance of the edge detection and thresholding technique. The Area Under the Curve (AUC) is 0.7952. As the value of AUC approaching to 1, the technique is considered as a good technique.

Table 2: Result of Image Before and After Image Enhancement Process with the Quality Measurement

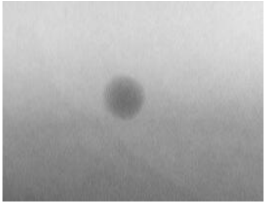
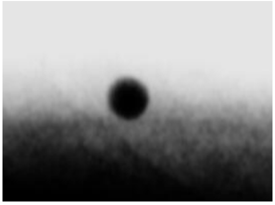
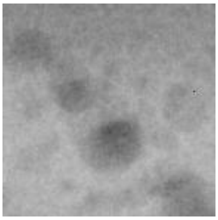
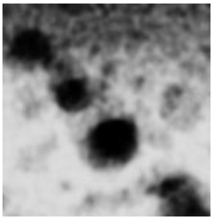
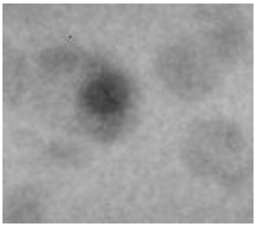
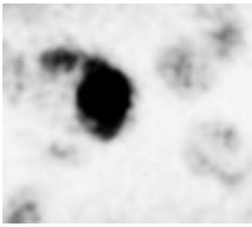
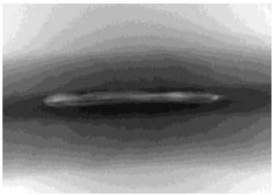
Original image	Processed image	Quality performance
		MSE=124.9122 PSNR=27.1648 NAE=0.25449
		MSE=98.2576 PSNR=28.2116 NAE=0.23426
		MSE=19.9580 PSNR=35.1296 NAE=0.037911
		MSE=15.2241 PSNR=36.3055 NAE=0.012723

Table 3: Original and Segmented Image

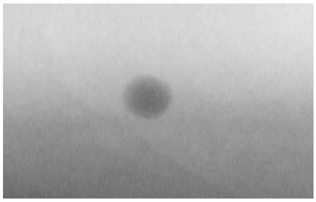
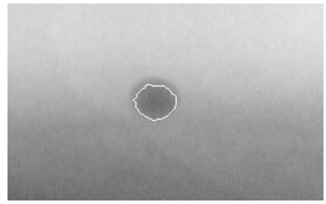
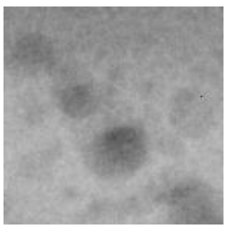
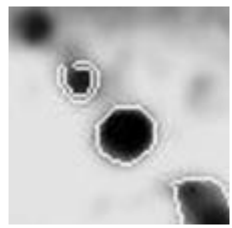
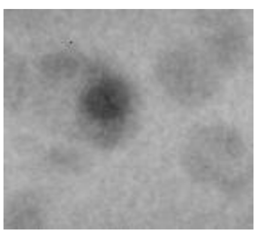
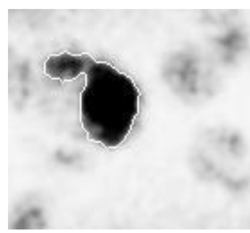
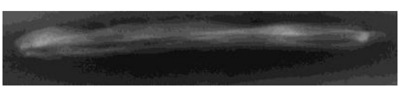
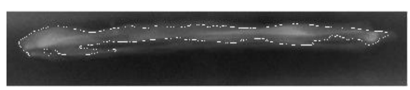
Original image	Segmented image
	
	
	
	

Table 4: Total Number of TP, TN, FP and FN

Reading	TP	TN	FP	FN
Total	12	3	6	1

Table 5: Value of Sensitivity and Specificity

Technique	Sensitivity	Specificity
Thresholding	0.923	0.667

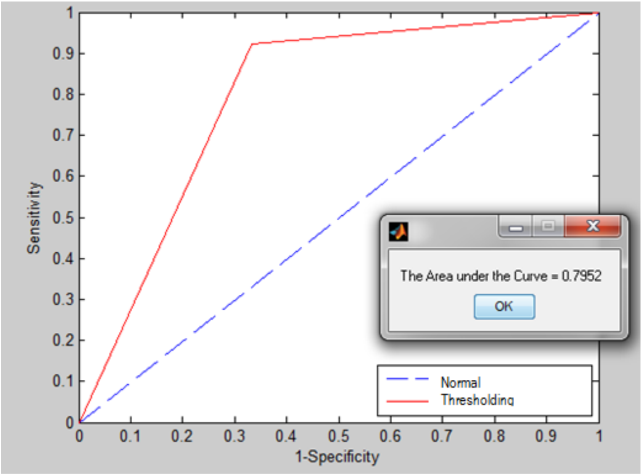


Figure 14: Graph of ROC Curve.

Conclusion and Recommendation

Radiographic image could consists of unwanted disturbance that could disturb the process of inspection. This could contribute to the difficulty in inspecting the discontinuity in the weldment. Digital radiography incorporates the element of image processing that could overcome the prbolem of low image quality by the process of noise removal and contrast enhancement. This processess improved the visual quality of an image. In this study, the quality of radiographic image is improved using Circular Average filter and logarithmic intensity contrast. Then, the weld discontinuities of porosity and slag inclusion are extracted from the image using edge detection and thresholding techniques. The accuracy of the detection process is evaluated by the value of AUC. All the processess indicate that all the objectives set up in this research are successfully achieved. There are some recommendations can be suggested for further development. Measurement of the exact length of discontinuity is important in order to determine the acceptance of the weldment. Hence, the exact length of discontinuity in the real specimen can be measured by exploring more on image properties aftter the process of image segmentation.

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