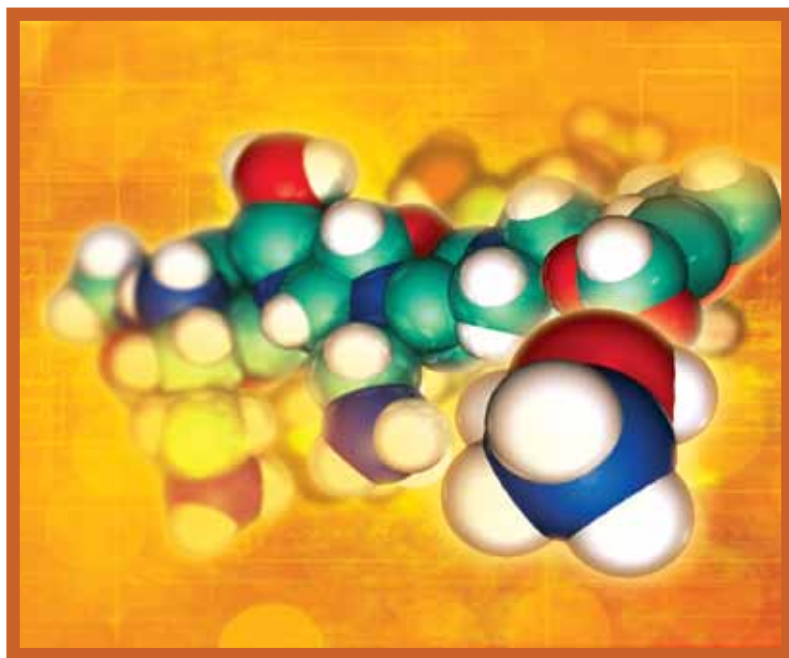


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Digital Radiographic Image Enhancement for Weld Defect Detection using Smoothing and Morphological Transformations

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ABSTRACT

Accurate inspection of welded materials is important in relation to achieve acceptable standards. Radiography, a non-destructive test method, is commonly used to evaluate the internal condition of a material with respect to defect detection. The presence of noise in low resolution of radiographic images significantly complicates analysis; therefore attaining higher quality radiographic images makes defect detection more readily achievable. This paper presents a study pertaining to the quality enhancement of radiographic images with respect to different types of defects. A series of digital radiographic weld flaw images were smoothed using multiple smoothing techniques to remove inherent noise followed by top and bottom hat morphological transformations. Image quality was evaluated quantitatively with respect to SNR, PSNR and MAE. The results indicate that smoothing enhances the quality of radiographic images, thereby promoting defect detection with the respect to original radiographic images.

Keywords: *Radiography, smoothing and morphological transformations, Signal to Noise Ratio, Peak Signal to Noise Ratio, Mean Absolute Error.*

Introduction

Radiography is the oldest and most widely used non-destructive testing (NDT) method for the effective detection of defects in materials [1-2]. Perpetual technological advancements has resulted in a significant increase in the use of Digital Radiography (DR), as opposed to conventional film radiography, in-line with increased computational analytical techniques through the digitization of images and their consequent readily achievable manipulation.

DR, also known as filmless radiography, has been widely implemented in many developed countries for more than 10 years, because it can enables immediate image analysis [3]. DR exhibits some disadvantages such as an inability to enable detection of small size (mm) of defects [4], it is expensive both to purchase and to convert existing film records into digital format. A further drawback is that DR is less sensitive than film radiography due to inherent random pixel noise due to image intensification coupled with poor image resolution. This lack of sensitivity is of significant concern in relation to the detection of defects in the resultant digital images.

It is common practice that a certified radiographer evaluates the quality of radiographic images visually, because it is easy, inexpensive and does not require any special equipment, however such inspections tend to be highly subjective, inconsistent [5], time consuming and labor intensive. The presence of noise and the low resolution of radiographic images have the potential to impair defect detection and it is thus of importance to perform image enhancement to mitigate disparity in radiographic image assessment. Improved image clarity should enable more rigorous and consistent radiographic image assessment with respect to defect detection.

This paper presents the results of a study pertaining to the enhancement of radiographic images using multiple techniques with respect to different types of defects. The techniques used to enhance image quality focus on noise removal and contrast improvement. Noise removal comprises of applying multiple smoothing techniques using median and average filters, whereas image contrast improvement is performed using top and bottom hat morphological transformations [6]. The resultant images are quantitatively evaluated with respect to quality using Signal to Noise Ratio (SNR), Peak Signal to Noise Ratio (PSNR) and Mean Absolute Error (MAE) analyses.

Image Processing

Image enhancement techniques reduce the noise by increasing the signal to noise ratio thereby improving the clarity of certain image features, which may be of significant interest to whomsoever is assessing it [7-9]. Conventional image enhancements include histogram equalization, image smoothing and direct grayscale transformation.

Image smoothing can remove noise and is an important first step in improving image quality [10]. According to Nicolae [11] noise removal is implemented to reduce the noise level and thus improve image quality enabling more accurate diagnoses. Of the well-documented noise removal techniques, median filtering is the most popular.

Median filtering is a smoothing technique which may be used to remove speckles and salt-and-pepper noise (impulsive noise) [12]. Such removal preserves sharp edges and image detail without loss of clarity, however it does not remove noise as efficiently as average and adaptive filtering techniques [13]. Median filtering comprises of replacing a pixel's gray level from $n \times n$ structuring elements (SE) with the median value of its neighborhood, which may be expressed mathematically according to equation (1).

$$K(i, j) = \text{median} \{I(i, j) \text{ is in } N(i, j)\} \quad (1)$$

where

$K(i, j)$ is the image after filtering process,

$I(i, j)$ is the original radiographic image,

$N(i, j)$ are the immediate neighbors of pixel $I(i, j)$ from $n \times n$ SE.

Average filtering replaces the value of a center pixel with the average value of the neighborhood pixels, equation (2). Both median and average filtering are based on $n \times n$ SE, which minimizes blurring of the image.

$$K(i, j) = \frac{1}{M} \sum_{(i, j) \in N(i, j)} I(i, j) \quad (2)$$

where

M is the total number of neighborhood pixels in $n \times n$ SE,

$N(i, j)$ corresponds to the pixels in the neighborhood of point $I(i, j)$ in $n \times n$ SE [14].

Although average filter able to reduce noise efficiently compared with median filter, but both normally result in eliminating thin lines and sharp corners in image and lead to blurring and distortion effects [15-16]. Due to the limitations of the two aforementioned smoothing techniques, it is proposed multiple smoothing and consequent morphological transformations with top hat and bottom hat. The techniques able to maximize the image contrast to make the defect more clearer from image background [17]. A clearly seen defect is very crucial in segmenting its boundary for defect detection [18]. The proposed technique may yield digital radiographic images of greater quality according to equation (3).

$$K * (i, j) = K(i, j) - (T(I(i, j)) + B(I(i, j))) \quad (3)$$

where $T(I(i, j))$ is the top hat and $B(I(i, j))$ is the bottom hat transformations that represented as in equation (4) and (5) respectively.

$$T(I(i, j)) = I(i, j) - \gamma(I(i, j)) \quad (4)$$

$$B(I(i, j)) = \rho(I(i, j)) - I(i, j) \quad (5)$$

for which

$\gamma(I(i, j))$ is the morphological opening on original image $I(i, j)$,

$\rho(I(i, j))$ is the morphological closing on original image $I(i, j)$.

Morphological transformations are used to improve image contrast, whereby the top and bottom hat filters correct for uneven illumination when the background is dark, Equation (4), and light, equation (5), respectively.

Methodology

A series of digital radiographic images taken of flawed specimens exhibiting different types of defects were acquired using an NDT Analyzer, Model: m 225D with digital image chain for enhanced contrast and superior resolution, Figure 1.



Figure 1: NDT Analyzer, Model: m 225D



Figure 2: SONASPECTION Flawed Specimen

Figure 2 presents an image of a flawed 12 mm thick carbon steel specimen manufactured by SONASPECTION (Serial Number: U-C-15), which was used to produce a digital radiographic image.



Figure 3: Interior of the NDT Analyzer

Figure 3 presents the analyzer interior, whereby the specimen is located between the image intensifier and the X-ray tube. The image enhancement algorithm developed and applied in this work was run under MATLAB R2009a. The flowchart for the image enhancement methodology is presented in Figure 4.

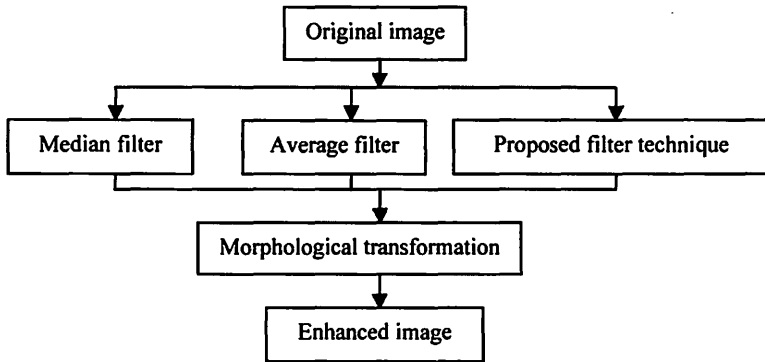


Figure 4: Image Enhancement Methodology Flowchart

The original image acquired from the analyzer is processed using median, average and proposed filtering before the morphological transformation of top and bottom hat are applied. Then, visual evaluation of enhanced images is performed by a certified welding radiographer followed by quantitative performance evaluation using Signal to Noise Ratio (SNR), Peak Signal to Noise Ratio (PSNR) and Mean Absolute Error (MAE).

SNR is a ratio of signal to noise strength, equations (7) and (8) respectively, and may be used to evaluate the degree of interference present in an image, equation (6). The ratio between two images in decibels is determined using PSNR, equation (9).

$$SNR = 10 \log_{10} \frac{signal}{noise} \quad (6)$$

where

$$signal = \frac{\sum_{i=1}^m \sum_{j=1}^n I(i,j)^2}{m \times n} \quad (7)$$

$$\text{noise} = \frac{\sum_{i=1}^m \sum_{j=1}^n K^*(i, j)^2}{m \times n} \quad (8)$$

$$\text{PSNR} = 10 \log_{10} \left(\frac{255^2}{\text{MAE}} \right) \quad (9)$$

MAE is used to measure the degree of image enhancement with respect to the enhanced and original images according to equation (10).

$$\text{MAE} = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n (K^*(i, j) - I(i, j)) \quad (10)$$

where

$m \times n$ is the image size (m rows, n columns),

$I(i, j)$ is the pixel value at (i, j) of an original image,

$K^*(i, j)$ is the pixel value at (i, j) of an enhanced image.

Results

The quality of the images obtained using the proposed filter technique is evaluated with respect to those acquired by only applying median and average filtering. Figure 5 presents four original radiographic images exhibiting different type of defects which are clustered porosity, slag inclusion and crack as shown in Image1, Image2 and Image4. While Image3 represents combination of two defects that are slag inclusion and crack.

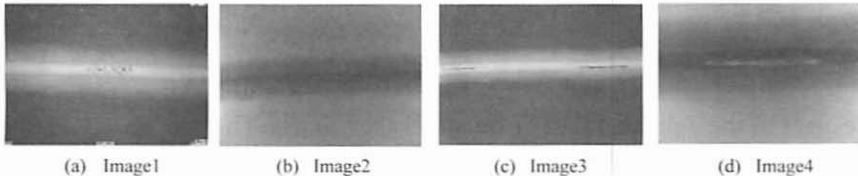


Figure 5: Original Radiographic Images

Figures 6 and 7 present the radiographic image after enhancement using median and average filtering followed by morphological transformations, respectively.

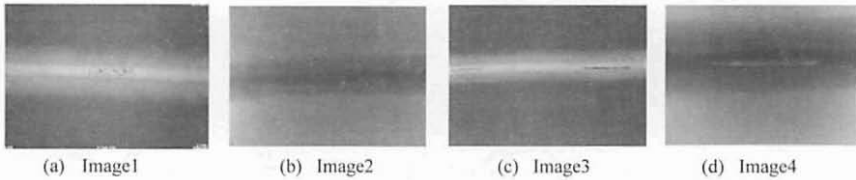


Figure 6: Radiographic Images using Median Filtering

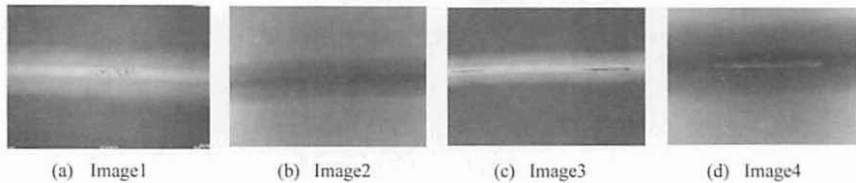


Figure 7: Radiographic Images using Average Filtering

Figure 8 presents the radiographic images after enhancement using the proposed combinatorial smoothing and consequent morphological transformations. It is evident that the defects are more prominent post-enhancement compared to the original images presented in Figure 5.

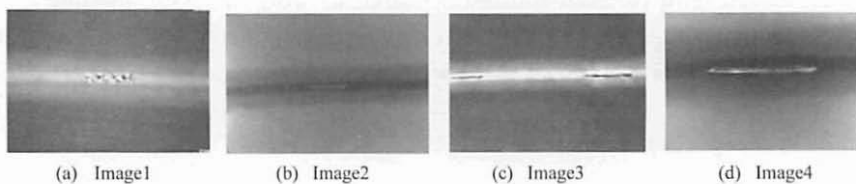


Figure 8: Radiographic Images using Proposed Technique

Table 1 presents the results for SNR, PSNR and MAE analysis with respect to the enhancement of Images 1, 2, 3 and 4. The proposed filtering technique exhibits a decrease in SNR and MAE with respect to the values for median and average filtering. The high PSNR values indicate that the proposed filtering technique produces good quality radiographic images.

Table 1: Image Enhancement Evaluation with respect to SNR, PSNR and MAE Analysis

Image	Quality	Median	Average	Proposed Technique
Image1	SNR (dB)	0.0034	0.0011	0.0011
	PSNR (dB)	28.5980	29.7500	29.4448
	MAE (dB)	2.5110	2.3202	1.9575
Image2	SNR (dB)	0.016	0.0177	0.0149
	PSNR (dB)	32.4167	32.5255	32.8589
	MAE (dB)	2.2907	2.2418	2.0505
Image3	SNR (dB)	0.000142	0.00005	0
	PSNR (dB)	26.4657	26.6161	27.0117
	MAE	1.9433	1.8362	1.5528
Image4	SNR	0.1576	0.1567	0.1549
	PSNR	28.5295	28.6455	28.7806
	MAE	3.3182	3.2618	3.1239

Figure 9 presents comparison of the SNR and MAE values for four enhanced radiographic images using median, average and the proposed filtering techniques; the lower the values the better the image quality.

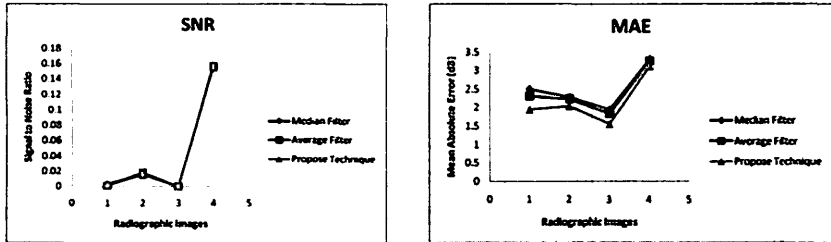


Figure 9: SNR and MAE for the Enhanced Radiographic Images

Figure 10 presents the results for the PSNR analysis for which higher values indicate better image quality.

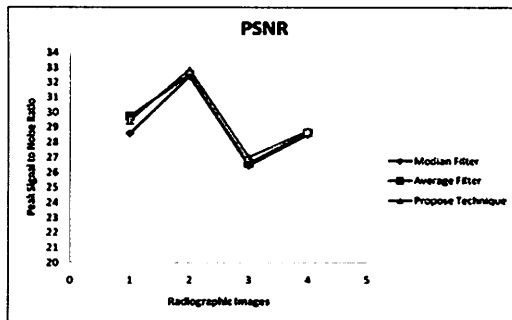


Figure 10: PSNR for the enhanced Radiographic Images

The SNR, MAE and PSNR analyses indicate that the proposed combinatorial filtering technique yields *better* quality radiographic images compared to those acquired using median and average filtering.

Conclusions

The enhancement of radiographic images for the purposes of identifying material defects is of significant importance. The presented work has determined that a combinatorial filtering technique, which incorporates both median and average filtering, yields better quality digital radiographic images than either of the two individual aforementioned filtering techniques with respect to SNR, PSNR and MAE analyses. The implications of this work are greater consistency, reduced subjectivity, reduced analysis time and improved efficiency in the detection and determination of material defects irrespective of the defect size. Future work based upon these findings should focus upon the development of an automated assessment system capable of rapid evaluation of material samples, which would increase efficiency and reduce costs.

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