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Image Processing Algorithm for Quantitative Characterization of Austenitic Stainless Steel Weld Defect in TOFD Images and Validation with Radiographs

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Abstract

Ultrasonic Time of Fight Diffraction(TOFD) is one of the advanced nondestructive testing technique for inspection of weld in Nuclear, Process Industries by providing very accurate quantization of defects. Inspite of acquiring data either manually or automatically the interpretation of data and defect characterisation is really a critical task which requires experienced Ultrasonic Testing(UT) personnel. The complexity increases as the volume of data increases and the results suffer error mainly due to human fatigue. The number of research has been conducted towards solving this problem and to automate the process. This paper proposes morphological image processing algorithm to achieve automation in segmentation and sizing of weld defects from TOFD data. The experimental results are compared with respect to standard radiographic method and are validated based on the performance measure viz., error and percentage error.

Keywords: Ultrasonic Time of Flight Diffraction(TOFD), segmentation, morphological image processing, defect detection, global thresholding, quantization

Introduction

Nondestructive testing is widely studied for testing structural materials in many industries. The ultrasonic TOFD is an advanced Ultrasonic technique that can replace other nondestuctive testing method[1]. TOFD is based on the measurement of the time of flight of the ultrasonic waves diffracted from defect tips and are used to characterise flaw in the structural material[2].

The data acquisition during TOFD inspection are achieved either manually or automatically. But most of the times the analysis and interpretation of data are done manually after inspection by the UT operator. This is a tedious, subjective process which purely depends on experience and knowledge of the operator. But as the volume of weld to be inspected increases the results may not be consistent due to human fatigue. To overcome the limitation of manual interpretation many researches have been initiated to position and measure the flaws. The automation of process by these techniques avoid repeated inspection resulting in more reliable and faster inspection.

In recent past the segmentation of TOFD images was implemented using neural network[3], rapid and accurate measurement of lateral and vertical location of defect in TOFD images are based on synthetic aperture focussing[4], TOFD image enhancement for recognition and weld detection[5], accurate defect detection by applying Winear filter and edge detection operator[6] and innovative procedures based on wavelet transform and texture analysis for automation of the sizing and positioning of flaw in TOFD images[7] are few applications of TOFD images. In this direction authors also have developed a tool for automation by exploring image processing technique for segmentation of flaw from its irrelavent background and its quantization. Finally the defect dimensions are validated with the radiographic results using performance measures.

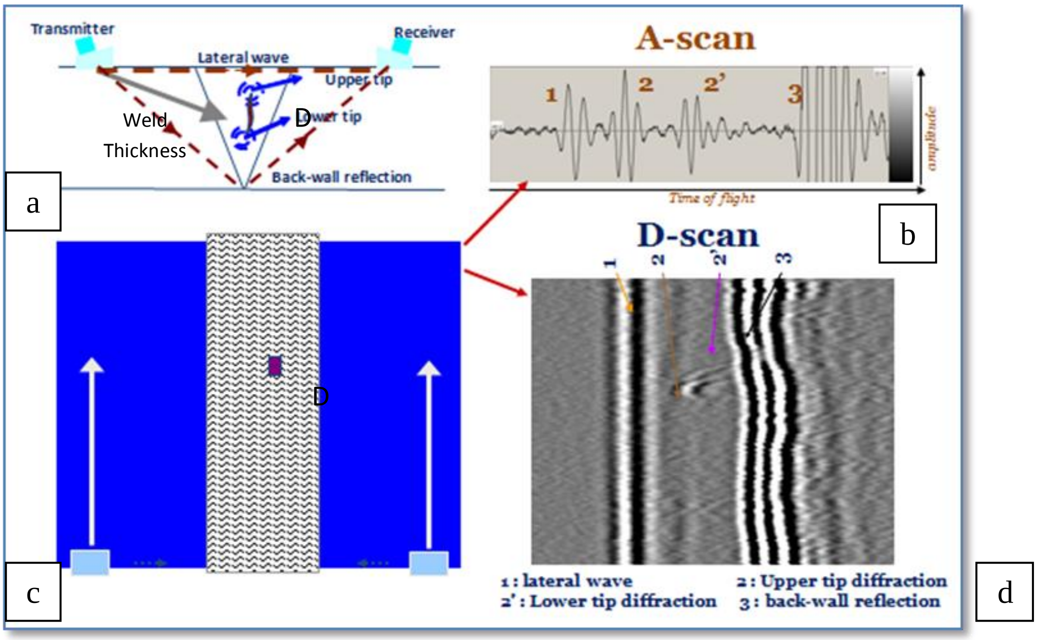


Figure 1 (a): TOFD Principle (b) Visuvalization of TOFD Scanning (c) A-Scan corresponding to defect D (d) D-Scan along the length of weld

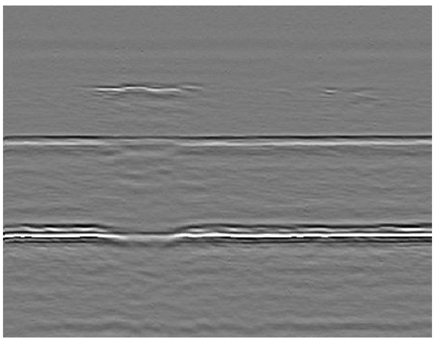
Image Acquisition

In this research two 25mm thick Austenitic stainless steel weld specimens of dimensions (200 x 200) mm were fabricated by SMAW welding process. The specimens were fabricated with two defined defects in such a way that they lie in two different halves along the length of the weld. The developed specimens are first examined by conventional radiographs and defects are characterized. These are kept as benchmark values. Later the specimens were examined by Ultrasonic TOFD method. The experimental study was conducted by the TOFD equipment model Microplus from AEA Technology, UK with a manual scanner consisting of 4MHz, 45º angle beam probe for longitudinal wave generation.

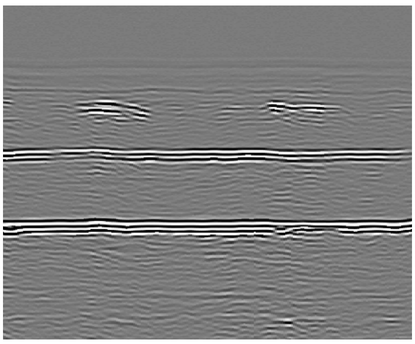
The TOFD principle with probe position is given in figure1(a). The visualization of TOFD scanning on the weld specimen with defect D is indicated in the figure 1(b). The scanning is performed in the direction of the arrow. During each step the UT signal starting from the transmitter is received as an A-Scan Signal with two/four indications from sound/ flawed weld region respectively [2]. The figure 1(c) indicates the A-Scan signal corresponding to the step where the defect D is present. The A-Scan signals at each instant are stacked together throughout the length of the weld to form the D-Scan image. The D-Scan image of the given weld indicating the presence of defect is given in figure 1(d).

Image Preprocessing

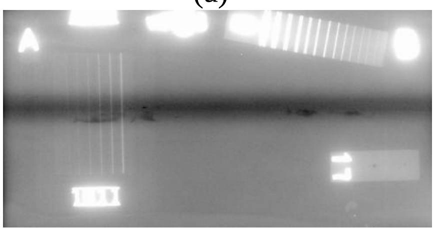
In order to improve the image quality and to ease further processing, digital images acquired need to be preprocessed. The initial step in image preprocessing is to branch the image into two equal halves along their length. This resulted in four different images. Further processing of these images was performed using MATLAB image processing tool[8]. The acquired images are in color domain the processing of which leads to computational complexity [10]. Hence the images are converted to gray scale image. The enhancement of the gray scale image was achieved by histogram equalization; a contrast enhancement technique that attempts to spread out the gray level in the image.



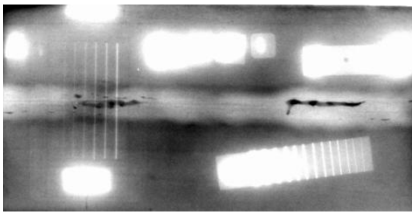
(a)



(b)



(c)



(d)

Figure 2: (a)ASS_1 TOFD Image (b)ASS_2 TOFD Image (c)Radiograph of ASS_1 (d)Radiograph of ASS_2

Segmentation

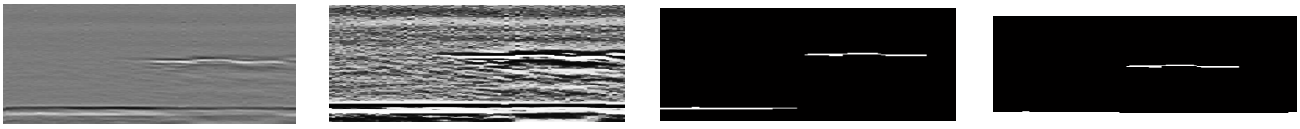
Segmentation is a process of partitioning a digital image multiple segments that is easier for future analysis [9]. The process should be stopped when the region of interest in an application have been isolated. These algorithms are generally based on few basic properties of intensities. In this work global thresholding a simplest segmentation method is used where grayscale image is converted into a binary image.

Morphological Image Processing

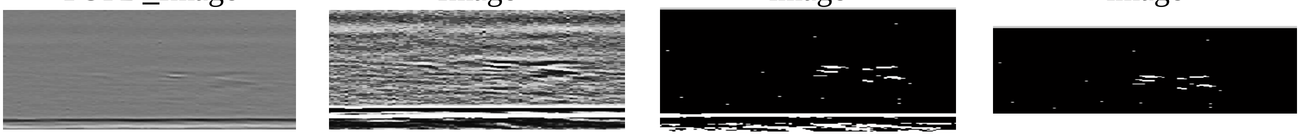
The image components that are useful in the representation and description of region of interest is extracted by mathematical morphology [10]. Dilation, region filling and erosion are used for connecting the gap between the pixels, filling with white pixels to differentiate the region of interest from background and removing the irrelevant details respectively [9]. The effectiveness of this image processing step purely depends on the chosen structuring elements.

Representations and Description

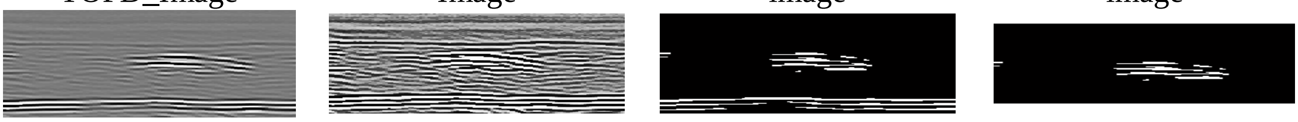
The quantitative defect characterization (representation and description) is achieved from the segmented image. The author has considered the major axis length of segmented flaw along the weld axis, as the characterizing descriptor.



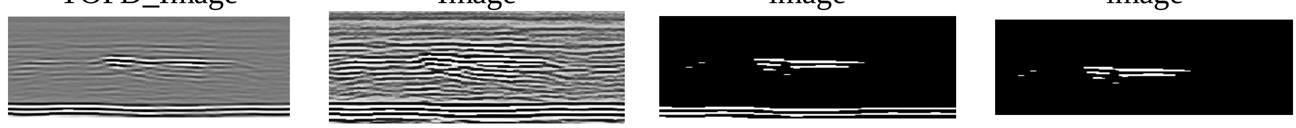
i(a) ASS_11 TOFD_Image | i(b) Preprocessed Image | i(c) Edge detected image | i(d) Defect Isolated image



ii(a) ASS_12 TOFD_Image | ii(b) Preprocessed Image | ii(c) Edge detected image | ii(d) Defect Isolated image



iii(a) ASS_21 TOFD_Image | iii(b) Preprocessed Image | iii(c) Edge detected image | iii(d) Defect Isolated image



iv(a) ASS_22 TOFD_Image | iv(b) Preprocessed Image | iv(c) Edge detected image | iv(d) Defect Isolated image

Figure 3: Steps of Segmentation

Results and Discussion

In the preprocessing stage the TOFD image of each weld specimen is branched into two images to obtain individual defects for further processing. The TOFD images viz. ASS_1 and ASS_2 are divided into ASS_11 & ASS_12 and ASS_21 & ASS_22 respectively and is given in figure 3i(a), 3ii(a), 3iii(a) and 3iv(a). The split images are converted into the grayscale image and enhanced by histogram equalization. The histogram equalized image for the four TOFD images are the preprocessed images given by figure 3i(b), 3ii(b), 3iii(b) and 3iv(b) respectively.

Table 1: Defect Characterization and Comparison

Weld specimen No	Length of the defect from radiograph (in mm) (Actual Value)	Length of defect from TOFD Image (in mm) (True value)	Error (in mm)	Percentag e Error (%)
ASS_11	35.35	29.52	5.83	16.50
ASS_12	34.24	32.28	1.96	5.72
ASS_21	37.80	20.14	17.66	46.73
ASS_22	36.01	37.40	-1.39	-3.85

The preprocessed image is converted into a binary image by applying global threshold value. The threshold value is selected after multiple trials. The binary image is given in figure 3i(c), 3ii(c), 3iii(c) and 3iv(c). The different mathematical processing steps are applied on to the binary image. The dilation stage bridges the gap by making use of the line structuring element between the edge pixels. The dilated images are region filled with holes and finally eroded. The sum of the pixels of each row was verified and a threshold value was optimized along the upper and lower side of the image to attain only the region lying between the lateral wave and the backwall echo and the remaining rows are eliminated. The final segmented image is given by figure 3i(d), 3ii(d), 3iii(d) and 3iv(d).

The major axis length of segmented flaw, along the weld axis was acquired. Thus the developed automated algorithm segments, as well as quantifies the flaw in the weld. The values of major axis length (True Value) of the defect, along with the results of radiographs (Actual Value) are tabulated in the table 1. The true values attained for the four TOFD images are validated with their actual values and results of the performance measures are tabulated in table1. The equation of performance parameters considered for validation in this research are given below

$$\text{Error} = \text{Actual Value} - \text{True Value} \qquad \text{-------------} \qquad (1)$$

$$\text{Percentage Error} = \frac{\text{Actual Value} - \text{True Value}}{\text{Actual Value}} * 100 \qquad \text{-------------}(2)$$

Conclusion

In this work a morphological image processing tool based on automation algorithm has been proposed for segmentation and quantification, the first of its kind for TOFD images. The segmentation algorithm extracts flaw ignoring the irrelevant details. The defect sizing algorithm quantifies the extracted defect by obtaining the characterizing descriptor. The flaw size is validated by comparing it with the radiographic result. On application of proposed algorithm, the percentage error value for defect characterization varies between 3.85 to 46.73 percentage. Though the algorithm allows segmentation of defects the percentage error does not remain to be consistent, as the effectiveness of the flaw segmentation algorithm purely depends on the proper selection of threshold and structural elements. Hence, the future work will concentrate on developing an algorithm that is image and parameter independent for best defect characterization in TOFD images.

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