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2D Gabor Functions and FCMI Algorithm for Flaws Detection in Ultrasonic Images

Kechida Ahmed, Drai Redouane, and Khelil Mohamed

***Abstract*—**In this paper we present a new approach to detecting a flaw in T.O.F.D (Time Of Flight Diffraction) type ultrasonic image based on texture features. Texture is one of the most important features used in recognizing patterns in an image. The paper describes texture features based on 2D Gabor functions, i.e., Gaussian shaped band-pass filters, with dyadic treatment of the radial spatial frequency range and multiple orientations, which represent an appropriate choice for tasks requiring simultaneous measurement in both space and frequency domains. The most relevant features are used as input data on a Fuzzy c-mean clustering classifier. The classes that exist are only two: 'defects' or 'no defects'. The proposed approach is tested on the T.O.F.D image achieved at the laboratory and on the industrial field.

***Keywords*—**2D Gabor Functions, flaw detection, fuzzy c-mean clustering, non destructive testing, texture analysis, T.O.F.D Image (Time of Flight Diffraction).

I. Introduction

NON destructive testing possibilities by ultrasonic imagery were hugely improved since new software, able to treat quickly the recorded signals and to create some specific images to this type of test were developed.

At the present time, ultrasonic data acquirements are automatically achieved. Analyses and interpretations are done inductively on cartography called ultrasonic image. The aim is to put to the fore and to characterize flaws in the material. The analysis of ultrasonic images is done manually by an operator. This latest selects images to analyze and research visually the presence of flaws. He then tries to determine precisely the position and the dimensions of these flaws.

Positioning and measuring operation can, at the present time be done by using algorithms and images processing techniques which were the topics of several research projects. The main objective of the survey is to set up algorithms allowing to the best interpretation data contained in an acquirement.

Non destructive data processing is at present very widely studied. It allows the exploitation of the information contained in these acquirements. The exploitation of theses information increases the sturdiness of the control tools and often avoids the multiple inspections necessary to detect defects.

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Authors are with the Welding and Control research center, Route de Dely-Ibrahim, B.P 64, Chéraga, Alger (e-mail: ahmed_kechida@yahoo.fr).

This article aims is therefore to study and to develop tools of image processing allowing detecting and localizing flaws (ex. cracks) present in metallic material. The achieved approach uses information based on the texture defect using 2D Gabor functions in an image, partner to a Fuzzy c-mean clustering classifier. A texture research allows detecting some partially visible flaws by an operator.

II. Time-of-Flight Diffraction (TOFD) Technique

A relatively recent ultrasonic NDT technique is the Time-of-Flight Diffraction (TOFD) method, which was first described by Silk (1977)[1]. This method relies on the diffraction of ultrasonic energies from 'corners' and 'ends' of internal structures (primarily defects) in a component under test. This is in contrast to conventional pulse echo methods, described above, which rely on directly reflected signals. The typical apparatus for a TOFD weld examination is shown in Fig. 1. Usually a two probe (one transmitter; one receiver) arrangement is used - the chosen transmitter producing a relatively wide beam spread to maximize the extent of the scan. The two probes are aligned geometrically either side of the weld and an A-scan taken at sequential positions along the length of the bead. The time taken to scan a length of weld is therefore very short since no raster scanning at each position is necessary.

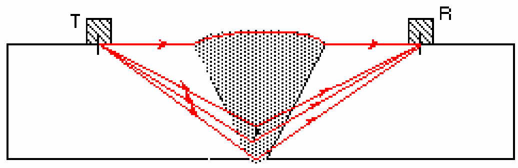

Fig. 1 TOFD probe arrangement for weld inspection

A schematic of an A-scan for the arrangement shown in Fig. 2 is given in Fig. 3. This shows the detection of four main signals - (1) the surface or lateral signal which travels along the surface of the component and has the shortest arrival time; (2) the top tip of the defect; (3) the bottom tip of the defect; and (4) the backwall echo, which has the longest transit time. Also present in the A-scan are reflections from mode converted signals which have a slower speed of propagation through the specimen and hence a longer transit time. Although mode converted signals are not usually examined in TOFD inspection, they can often duplicate the main body of the A-scan. If both tips of a defect can be resolved in the A-scan then the actual depth and 'through-wall' thickness of the flaw can be accurately calculated (Silk, 1977; Carter 1984).

This was the main thrust behind the development of the technique, since other methods, such as standard pulse echo techniques could often locate but not size defects accurately.

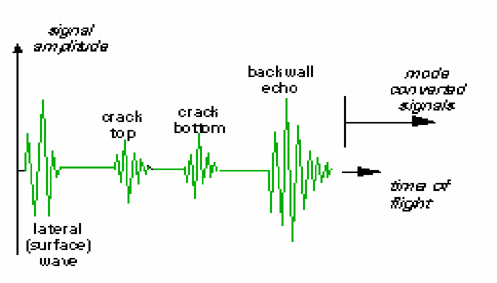

Fig. 2 Schematic of TOFD A-scan

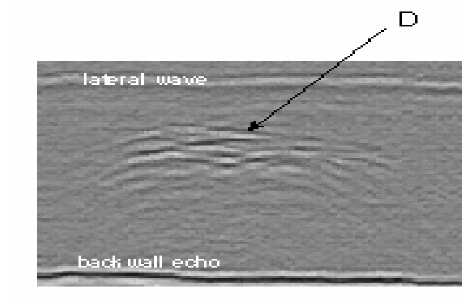

Fig. 3 TOFD D-scan of butt weld and defect

TOFD has some drawbacks in that it is rare to achieve clear signals in the A-scans due to the nature of the weak diffracted signals, coupled with noise, and interference from signals derived from very small pores or non-uniformity in the weld region. However, one of the reasons why TOFD examination has attained widespread use is the associated data acquisition and presentation methodologies proposed very early in its development by Silk (1977). Each A-scan is digitized as it is collected by the receiver, to a resolution of 8 bits - the signal is not rectified and instead is mapped directly to the 256 possible grey levels. A series of A-scans, for a section of weld, is then presented in B or D-scan fashion as shown in the example scan in Fig. 3. In this example scan we can clearly see the lateral wave (at the top), and the mass of backwall echoes (at the bottom). Also present between these signals is a defect, D, around which are peculiar down curved arcs which are typical of TOFD signatures. The arcs are caused by the interaction of the defect with the wide beam spread when the probes are not exactly in line with the flaw - hence the signal becomes progressively stronger near the centre of the arc as the actual position of the defect reaches the centre of the ultrasonic beam. Since the signals associated with the presence of defects are often quite characteristic when shown in Silk's D-scan plot, the TOFD technique is also now extensively employed for defect detection as well as sizing (Silk, 1984), and has also recently been used to completely replace other NDT methods (Verkooijen, 1995).

III. Texture Features Based on Gabor Functions

The Gabor functions are Gaussian shaped band-pass filters, with dyadic treatment of the radial spatial frequency range and multiple orientations, which represent an appropriate choice for tasks requiring simultaneous measurement in both space and frequency domains [2]. The Gabor functions are a complete (but a no orthogonal) basis set given by:

$$f(x,y)=\frac{1}{2\pi\sigma_x\sigma_y}\exp\left(-\frac{1}{2}\left(\frac{x^2}{\sigma_x}+\frac{y^2}{\sigma_y}\right)\right)\exp(2\pi j\mu_0 x) \quad (1)$$

Where σ_x and σ_y denote the Gaussian envelope along the x and y-axes, and μ_0 defines the radial frequency of the Gabor function.

Each Gabor filter has a real and an imaginary component that are stored in $M*M$ masks, called R_{pq} and $\mathbf{I}_{pq}$ respectively, where $p = 1, ..., S$, denotes the scale, and $q = 1, ..., L$, denotes the orientation. In our work we use $S = 8$ scales, and $L = 8$ orientations, with $M = 27$.

The Gabor filters are applied to the TOFD image **W**. The filtered images $\mathbf{G}pq$ are computed using the 2D convolution of the TOFD image with the Gabor masks as follows:

$$\mathbf{G}pq = [(\mathbf{W} * \mathbf{R}pq)^2 + (\mathbf{W} * *\mathbf{I}pq)^2]^{1/2} \quad (2)$$

Where $*$ denotes the 2D convolution operation.
The Gabor features for etch pixel are given by filtered images $\mathbf{G}pq$ as shown in Fig. 4.

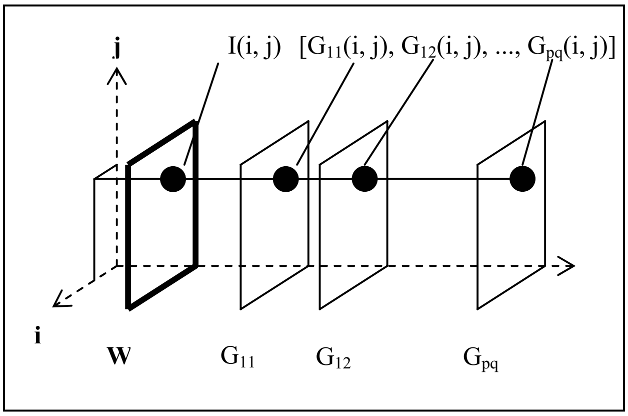

Fig. 4 Features selection for etch pixel in TOFD image

IV. Fuzzy C-Means Iterative Algorithm (FCMI)

The method of FCMI is a method of supervised classification, it uses the concept of fuzzy logic, it is given by the following algorithm [3]:

a) N_c clusters are initialized with random patterns in the features space.

b) Calculation of the distance between each pattern and each cluster centre: $d_{ij} = \|x_j - y_i\|$ (3)

c) Calculation of the memberships function μ (**fuzzification**):

$$\mu_{ij} = \left[\sum_{l=1}^{N_c} \frac{d_{ij}^{2/(\beta-1)}}{d_{lj}}\right]^{-1} \quad (4)$$

β is a tuning parameter which controls the degree of fuzziness in the process.

If $d_{lj} = 0$ for $l = l_0$ then $\mu_{l_0 j} = 1$ and ($\mu_{ij} = 0$ for $l \le i \le N_c$ and $i \ne l_0$).

d) The cluster centers change by using the following formula:

$$y_i = \frac{\sum_{j=1}^{m} \mu_{ij} . x_j}{\sum_{j=1}^{m} \mu_{ij}} \quad (5)$$

With m: the number of patterns.

e) If the new cluster centers are changed, then we move at the stage b) else we continue.

f) **Defuzzication:** if $\mu_{i_0 j} = \max(\mu_{ij})$ then $\mu_{i_0 j} = 1$ and ($\mu_{ij} = 0$ for $l \le i \le N_c$ and $i \ne l_0$). The form x_j belongs to the class i_0.

In our work we have tow class **'defects' or 'no defects'** and we chose β = 1,03.

V. Expermentation and Result

To check up the strength of the proposed approach, we have applied it on three images realized in the laboratory. These images represent the result of an automatic U.S. control of material with some known geometric defects in it. The Fig. 5 chows the results obtained and they are jugged very interesting for a potential industrial application.

To validate the results, we have tested the developed approach on a three images realized on an industrial plant (Fig. 6). It is a B scan image of an aluminum weld with 4 cracks illustrated by Fig. 6a. The result of the first step of the algorithm localizes the lateral back wall wave of the sample and the four defects (cracks type F1, F2, F3, F4). The second step of the algorithm is illustrated by the segmented image obtained (Fig. 6c), where we can see the development of the defects with regards to the back ground image.

The Fig. 7a is the B scan image of a steel block butt joint weld with 3 defects:

Defect D1: opened lack of fusion

Defect D2: opened cracks

Defect D3: closed lack of fusion

The result obtained is illustrated at first by Fig. 7b where we can notice (establish) the detection of the creeping wave expressing the lateral echo, back wall echo and the localization of the three defects (boxed in red line).

The Fig. 7c show the segmented image binarised at two levels and the developpement of the three defects (white) and the back ground (black).

With the same way, we have tested the efficiency of the algorithm on another image B scan (Fig. 8a). This image illustrates the result of the control of a steel block butt weld with three real defects.

Defect D1: opened crack

Defect D2: slag

Defect D3: closed lack of fusion

Figs. 8b and 8c represent respectively the results of two steps of the algorithm: (localization and segmentation). The same remarks should be put to the fore.

The first problem raised by this kind of images is to localize the echo of the front and those of the back wall of the sample. However we can notice that these areas were detected. Concerning the defects the algorithm is strong enough to allow a proper (correct) detection.

VI. Conclusion

The proposed approach is based on the 2D Gabor functions partner to a Fuzzy c-mean clustering classifier. We consider that the method proposed in this article is fast and reliable. The combination of these two parameters allows being endowing of a robust and efficient means in detecting flaws from an ultrasonic image of T.O.F.D type in non destructive testing of a material.

In the future we consider developing other techniques for the measurements and the identification of the defect in the T.O.F.D images.

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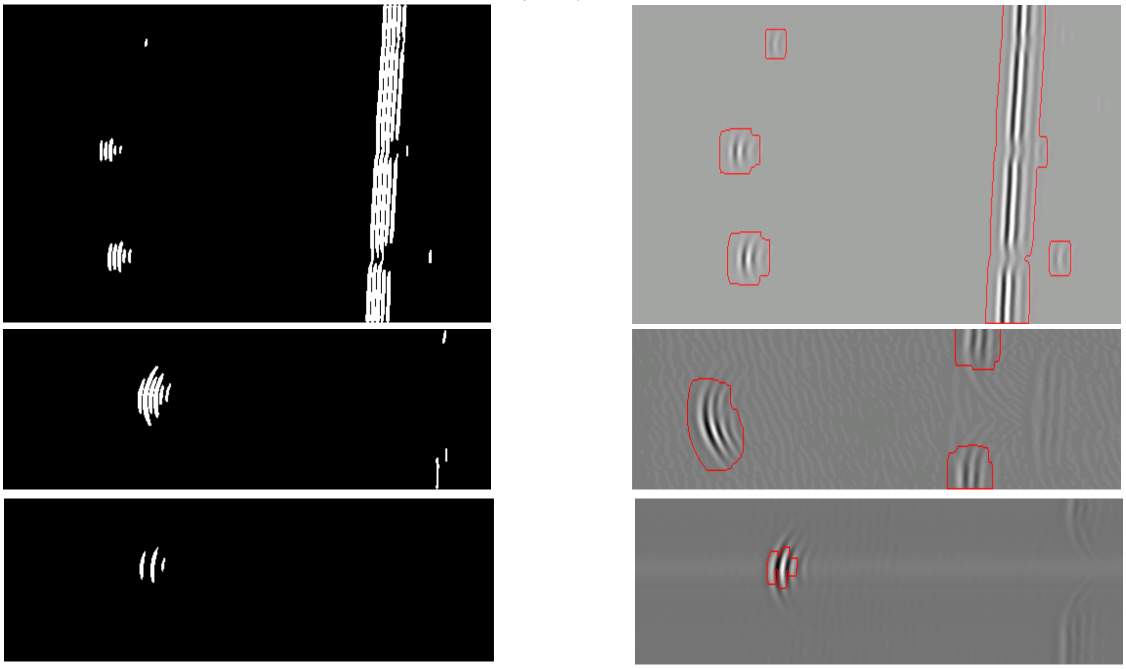
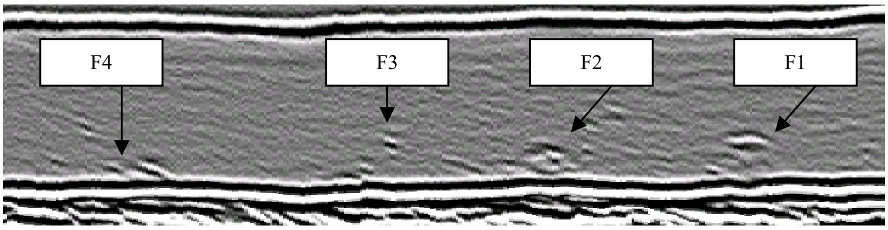
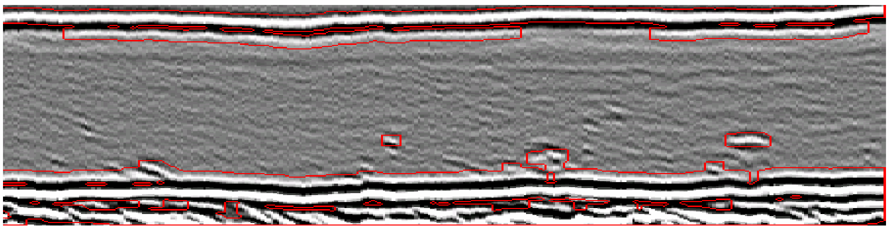


(a) (b)

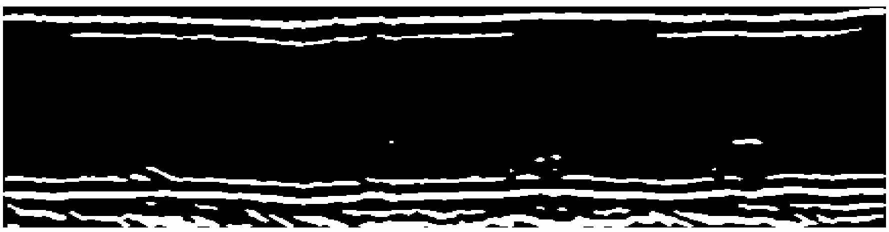
Fig. 5 Segmentation results of laboratory TOFD images



(a)



(b)



(c)

Fig. 6 Segmentation results of TOFD image (6a)

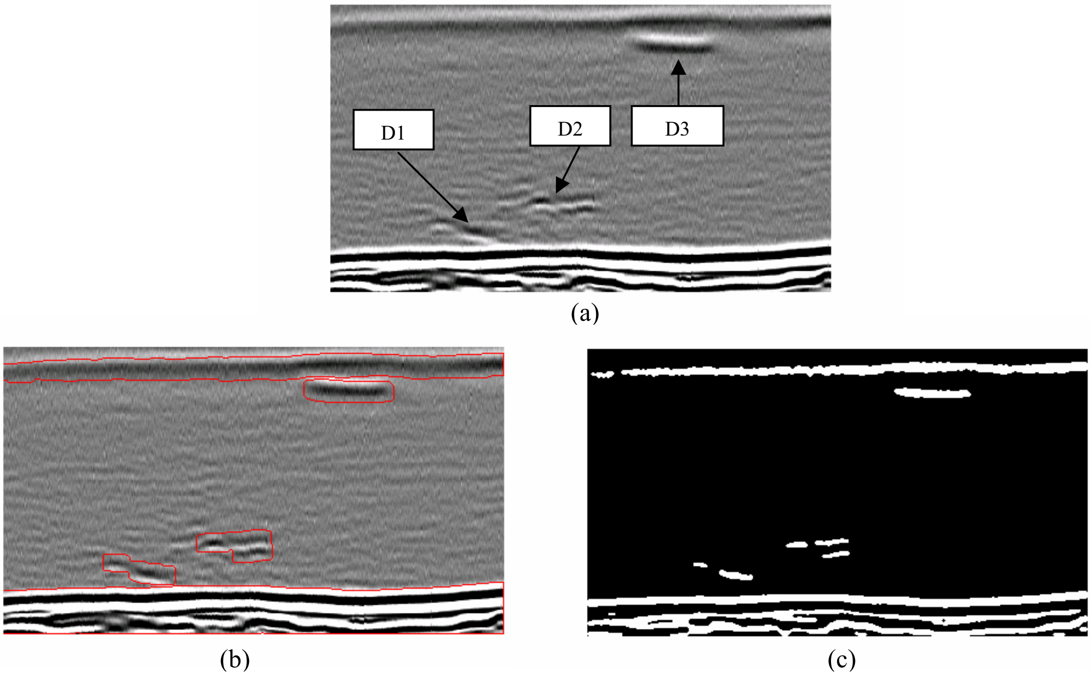


Fig. 7 Segmentation results of TOFD image (7a)

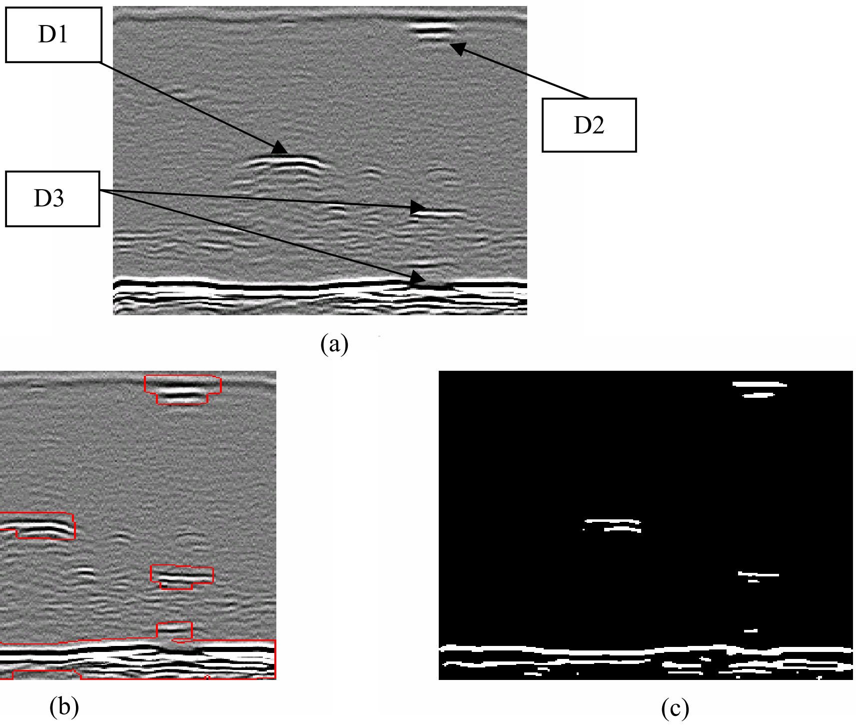


Fig. 8 Segmentation results of TOFD image (8a)