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Ultrasonic Image Enhancement to Internal Defect Detection during Material Inspection

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Abstract. Ultrasonic waves are efficiently exploited to detect internal defects such as cracks and occlusions in non-destructive testing (NDT) of materials. In some automated procedures, emitter and receiver probes are displaced step by step and signals are displayed to form images that make diagnosis easier to interpret. However, too much images are unnecessarily stored when they correspond to safe zones (without presented defects). In this paper, we propose a method that enhances ultrasonic images quality in order to improve the discrimination between images containing or not a shape regarding a detected defect. The method is based on the adapted histogram equalization technique followed by morphological operations that erase all useless shapes on processed images.

1 Introduction

Non Destructive Testing of Materials consists in inspecting the integrity of a structure without causing damages in order to preserve its future use. Ultrasonic waves are exploited for this purpose because of their safety and their low cost [1]. The principle of ultrasonic inspection is based on analyzing produced waves when an incident one interacts with a discontinuity (defect) presented in the structure under control. Principally, three types of waves are generated: reflected one, refracted one and diffracted one [2]. Diffracted waves present the advantage to propagate all around the defective zone. This makes their detection less dependent of the receiving probe position. However this type of waves is generated only by acute tips. That is why crack defect detection benefits by this wave exploitation in the Time of Flight Diffraction named technique (TOFD) [3].

Nowadays, the graphic performances allow quick image formation and visualization. So ultrasonic signals are digitalized and stored to form ultrasonic images easier to interpret and shapes regarding internal detected defects may be analyzed. Locating, dimensioning as well as characterizing are thus deduced by exploiting existing image processing techniques [4,5,6]. This facilitates the decision making and allows more robustness and reliability in the defect recognition.

In the case of TOFD image, as diffracted wave propagates in all directions around the discontinuities, its energy is significantly dispersed. Thus, resulting observed signal amplitude is relatively low involving low contrast in the formed images. The forms regarding presented defects may be difficult to observe. In order to increases the capacities of the detection [7, 8, 9].

Even though the mass storage is becoming increasingly more important, we think that classifying formed images in “defective zone “ and “non defective zone” as their formation is suitable and will avoid the storage of a huge of useless images. This will allow saving memory and time. Pattern recognition techniques also give a substantial help in this domain when they are applied to defect shape recognition [10,11]. For this purpose, the first processing step consists in discriminating the different shapes presented in the analyzed image and eliminating background noise.

This paper presents a proposed method to extract principal feature presented in a TOFD image by histogram analysis and mathematical morphology application. In a first step, adaptive histogram equalizing technique is exploited in order to enhance the contrast and to recognize gray levels regarding significant presented shapes. Thus, the image is region segmented consequently and erosion and dilatation morphological operators can be successively applied to eliminate background irregularities while maintaining the resulting shapes at their effective sizes.

Next section of this paper describes briefly the TOFD inspection technique. In section 3, the technique to enhance image contrast by exploiting adapted histogram and morphological operators is developed. The results obtained on a TOFD image presenting a crack defect are shown in section 4. Section 5 summarizes the conclusions.

2 TOFD image formation

TOFD images are synthesized during ultrasonic inspection techniques by exploiting diffracted waves. Each row of these images is constituted by the samples of a received signal during the scanning of the structure under control [3]. Two probes are used: one emitting ultrasonic pulses, the other receiving diffracted waves that are generated at tips of presented discontinuities. Those two probes are maintained at equal distances and are displaced step by step, according to a straight line. At each position, the received signal is digitized and his samples will constitute the pixels of one row in the formed image. The amplitudes are displayed in grey levels, black for negative values, grey near the zero and white for maximal ones. Thus, images obtained scanning safe zones (no defect) will be uniformly grey while a white shape will appear in the image in a defective zone. Indeed, in safe zones, signals are constituted only by noise, while signal amplitude will increase in case of a presented discontinuity that has refracted the emitted ultrasonic wave. Figure 1 shows an example of a TOFD image. As both surface and the back-wall of the controlled structure produce at each probe position reflected waves (Fig. 1 (a), on each row of the image it will appear at the same columns white and black pixels regarding maximum and minimum amplitudes, forming thus the corresponding lines in the image (Fig. 1. (b), The pulse regarding a detected defect (between surface and back-wall echoes) produces a shape that can give

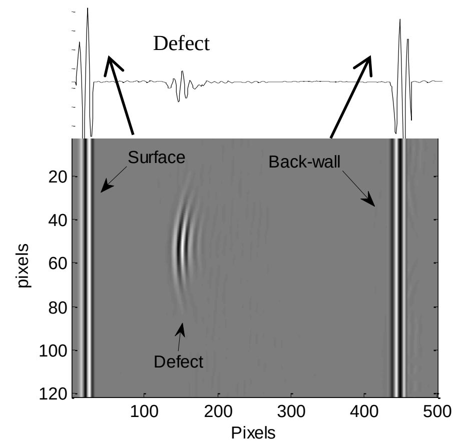

Fig 1. At each position, the samples of the received A-scan signal are displayed as pixels of a row in the formed image.The level of the grey depends of the sample amplitude. Vertical white and black lines result from surface and back-wall echoes.

The defect location is proportionally deduced by the position of its corresponding shape between surface and back-wall echoes.

3 Image enhancement

Because diffracted waves propagate all around the defective area, their energy is dispersed also all around. That implies low amplitudes in representative signals, so low contrast in the formed images. The defect detection and characterization accuracies depend largely of an enhancement pre-processing phase. In this section, the histogram equalization based technique to image enhancement is described as well as its improved version.

3.1 Histogram equalization

A histogram is a graph that shows frequency of occurring of pixels intensities in the whole image [8, 9]. When a region is constituted only by noise, each pixel value has the same probability to occur. If the gray-level histogram corresponds to an image I(x,y), composed of light objects in a dark background, object and background pixels will have grey levels grouped into two dominant modes.

Extracting objects from background returns to select a threshold *th* that separates these modes. Then any point *(i,j)* for which *I(i,j) > th* is called an object point, otherwise, the point is called a background point.

Histogram equalization allows to enhance image quality by removing superimposed dark or light fog. Equalizing the histogram leads to making it as flat as possible and apportioning initial image grey levels all over the grey level band *L*. (L=256 in most of cases). Resulting equalized histogram *p* is calculated as follows:

$$P_n = \frac{\text{number of pixels with intensity } n}{\text{total number of pixels}} \qquad (1)$$

$n = 1, 2, 3, \ldots, L-1$

And the resulting image

$$g(i,j) = (L-1)\sum_{n=0}^{I(i,j)} p_n \qquad (2)$$

The histogram equalized image *g* will be defined by

$$g(i,j) = (L-1)\sum_{n=0}^{I(i,j)} p_n \qquad (3)$$

where floor() rounds down to the nearest integer. This is equivalent to transforming the pixel intensities, *k*, of *f* by the function

$$T(k) = floor((L-1)\sum_{n=0}^{k} p_n \qquad (4)$$

The motivation for this transformation comes from thinking of the intensities of *f* and *g* as continuous random variables *X*, *Y* on [0, L − 1] with *Y* defined by:

$$Y = T(X) = (L-1)\int_0^x p_x(x)\,dx \qquad (5)$$

where p_x is the probability density function. *T* the cumulative distributive function of *X* multiplied by *(L−1)*.

Figure 2 illustrates an example of envelopes of an histogram, before and after equalizing (respectively in (a) and (b)).

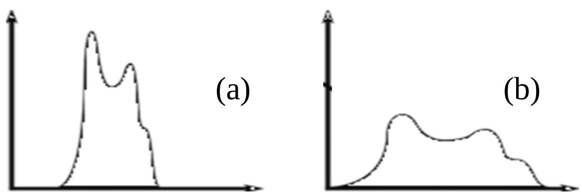

Fig 2. Example of histogram before equalization (a), and after equalization (b).

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While the histogram operates on the entire image, adaptive histogram operates on small regions. Thus, each region's threshold is determined depending on local image characteristics. This allows to increase contrast and facilitates detection and recognition of presented shapes. The neighboring regions are then combined using interpolation in order to eliminate induced boundaries. The contrast, especially in homogeneous areas, can be limited in order to avoid amplifying the noise which might be present in the image.

3.2 Morphological operations

Erosion is a basic morphological operation that is exploited to eliminate noise in binary images [12]. Its principle consists in scanning the image by using a structuring element with a specific form that depends on the shape to select or to suppress. The structuring element is constituted by a group of pixels and has its origin at the center. It is shifted over the image and at each pixel of the image its elements are compared with the set of the underlying pixels. If the two sets of elements match the condition defined by the set operator (*e.g.* if the set of pixels in the structuring element is a subset of the underlying image pixels), the pixel underneath the origin of the structuring element is set to a pre-defined value (0 or 1 for binary images). This operation, while eliminating artifacts, reduces processed shapes. That is why it is often followed by the dilatation operation that uses the same structuring element to enlarge the boundaries.

4 Application and results

In this work a TOFD image has been formed by displacing the tandem of emitting and receiving probes on a structure where a crack is simulated by a drilled hole as illustrated in figure 3. Indeed, the circular sides reflects incident waves all around the axis just like diffracted ones. This is why this type of waves are generaly simulated by drilled holes.

The probes are moved step by step, 0.5mm 120 times producing 120 ultrasonic signals that have been used to synthetize the image constituted thus by 120 rows.

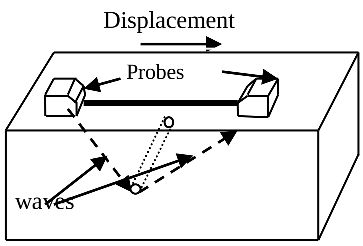

Fig 3. A TOFD inspection description. The receiving and emitting probes are moved step by step according to a staright line as shown by the arrow.

Figure 4(a) shows the formed image where surface echoes have been ignored. The arc of barabola corresponds to reflected waves by the drilled hole.

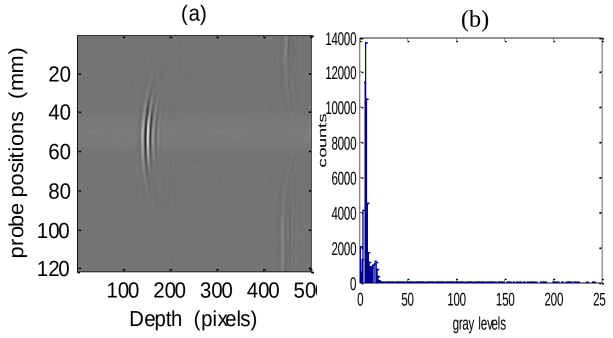

Figure 4. (a): Tofd image, formed by simulating a crack defect by a drilled hole. (b): Histogram of the image represented in (a).

The histogram of this image has been equalized (Fig.5 (a)) and the resulting image is shown in figure 5(b). In addition to defect shape (set of parabolas), the drilled hole as well as back wall echoes are visible, confirming the efficiency in image enhancing by equalizing histogram.

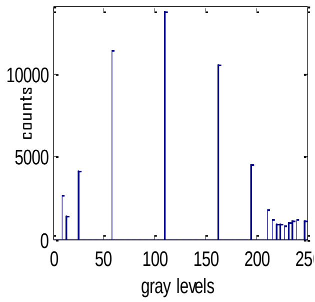

Fig 5 (a). Equalized histogram previously processed.

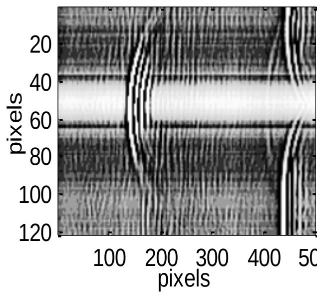

Fig 5 (b). Resulting image.

Considering the resulting histogram, it appears that significant gray levels are peaks between 50 and 200. So, the binarization can be performed by cancelling insignificant pixels (gray levels greater than 200 and less than 50). Figure 6(a) shows obtained binary image where the pertinent features are discriminated: namely the drilled hole, the reflected waves that simulate the diffracted ones and the backwall echoes (at the right of the image).

Background noise has been removed by exploiting erosion technique as explained in previous section. The structuring element has been chosen as a disk of 2 pixels radius because the most important shape (that is regarding reflected waves) is curvature. As all shapes are thus eroded, a dilatation phase has to be performed in order to recover effective sizes of the features. Figure 6(b) illustrates resulting processed image.

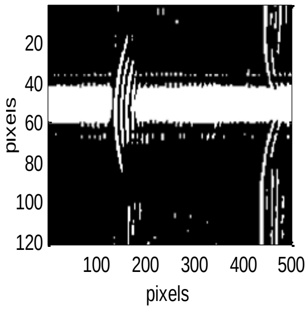

Fig 6 (a). Binarized image obtained by cancelling all pixels of gray levels that are different from those selected by the peaks of the equalized histogram.

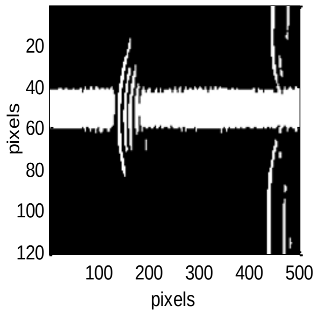

Fig 6 (b). Resulting image after the erosion/dilatation phases.

At this stage, it becomes easier to exploit pattern recognition techniques to parabolas detection in order to automate diffracted waves detection. Indeed, parameterized forms may be detected by least mean square algorithm, as well as RANSAC filter [6]. This phase will totally automate this type of control.

5 Conclusion

During automatic procedures of non destructive testing of materials, a large amount of images are synthetised. Their interpretation is widely dependant of their quality, especially when diffracted waves are exploited. Indeed, these waves are of low amplitude because of their energy dispersion all around a presented discontinuity. However, making the detection independant of the probes positions, diffracted waves are suitable for crack detection. In this paper, it has been shown how the exploitation of histogram equalization and morphological operations enhances contrasts and discriminates efficiently presented shapes in the image. By improving the quality of produced TOFD images in an automated material inspection facilitates control diagnosis.

References

1. R.A. Blake, & J.P. Allebach, Digital ultrasonic image construction using electronic ordered dither techniques, J Nondestruct Eval. 1981 pp 2- 75.
2. J. Krautkramer and G.Simpson. Ultrasonic Testing of Materials. Springer Science and Business Media. 2013.
3. M.Silk, The potential of scattered or diffracted ultrasound in the determination of crack depth", Research techniques in NDT, vol 3, June 1975.
4. X. Gao, Y. Shen, & Luo, L. Noise Reduction Method for Ultrasonic TOFD Image Based on Image Registration ,J Nondestruct Eval 325-330. 2013 doi:10.1007/s10921-013-0185-9.
5. R. Gonzalez, C.and. R.E. Woods Digital image Processing ", Third Edition, 2008.
6. Hornberg A.Handbook of Machine vision. Wiley VCH (2006)
7. P. J. Janani Premaladha and K. S. Ravichandran Image enhancement techniques: A study Indian Journal of Science and Technology, vol. 8 issue 22. doi: 10.17485/ijst/2015/v8i22/79318
8. R.Maini andd A. Himanshu A Comprehensive Review of Image Enhancement Techniques. journal of computing, volume 2, issue 3, march 2010.
9. P. Janani, J. Premaladha and K. S. Ravichandran Image enhancement techniques: A study, Indian Journal of Science and Technology, vol. 8, issue 22, doi: 10.17485/ijst/2015/v8i22/79318
10. P.A Petcher. and S. Dixon Parabolas Detection using Mached Filtering for Ultrasound B-scans. Ultrasonics.vol. 52 pp 138-144. (2012).
11. S. Singh, & M. Kaur, Machine vision system for automated visual inspection of tile's surface quality. *IOSR J Eng*, vol. 2issue 3, pp 429-432, 2012.
12. J. Serra P. Soie Morphological mathematics and its applications to image processing. Springer Science and Business Media. 2012.