Steps Toward Automated 3D Evaluation of Ultrasound Data

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Abstract. Ultrasonic image segmentation is a focus point for research in clinical and industrial application. Our objective is to achieve automatic or semi automatic data evaluation without expert intervention. While most work was done on one and two dimension data, this paper deals with the automatic evaluation of three dimensional ultrasonic images. An approach is proposed and applied on Carbone Fiber Reinforced Polymer (CFRP) specimen.

1. Introduction

Ultrasonic inspection technology finds increasing application as a safe non destructive testing method in industrial and medical fields. Inspection with ultrasound waves is highly recommended when applicable due to its safety, economic efficiency and effectiveness in detecting discontinuities. Different modes of inspection are being used. The Pulse/Echo inspection is based on the evaluation of reflected signals. Reflections come from surface and backwall of the inspected part. In case of presence of discontinuities, the difference between acoustic impedance of the material and discontinuity provokes a reflection of the incident signals. By analyzing the received signals conclusions are made about the quality of the inspected specimen. To facilitate this task, different modes of imaging, mostly B and C scans are used. In such images, the appearance of geometric boundaries of discontinuities is dependent on the acoustic impedance difference between material and defect, on the assumption of usage of the true speed of sound in the material, which can significantly influence the obtained signal, and on the characteristics of the inspected material. Nevertheless, the generated ultrasonic images are always criticized for their poor signal to noise ratio and noisy appearance.

Speckle noise affects ultrasound images giving them their granular texture appearance. It is formed from backscattered echoes of either randomly or coherently distributed scatters in material.

Most work about dealing with speckle noise is done in medical applications of ultrasonic inspection. Models of distribution of speckle noise were proposed depending on the statistical properties of the received echo signal which in their turn depend on the density
and spatial repartition of scatterers. Rayleigh distribution is proposed as an appropriate model in case when there are a large number of randomly located scatterers [1]. In the case of partially developed speckle, where there is a low effective scatterer density, the K-distribution is an appropriate model [1], and when there is a coherent component that might, for instance, account for regular structures in tissue, the Rice distribution is appropriate [1], [2]. A recent paper by Tao et al. [3] has compared the validity of four families of distribution (Gamma, Weibull, Normal and Log-normal) of speckle noise on clinical cardiac images acquired from machines with different settings. [3] concludes that the Gamma distribution had the best fit to the data and gave the lowest misclassification rate between tissue and blood. This distribution was adapted by Thangavel et al. [4] where the author compared 16 different noise removing algorithms applied on medical ultrasonic images of prostate. Results showed that a hybrid filter of the mean and the median filters (M3 filter) performed better than others filters. Kotropoulos et al. [5] applied Support Vector Machine (SVM) on medical B-scans to distinguish between lesion and background.

In industrial application of ultrasound, different techniques are used in order to analyse the received signal (A-scans) and to segment the images (B or C scans). No standard method exists though, following are resumed some of the ideas being applied. For A-scans of welds, Discrete Wavelet Transform (DWT) was used by Matz et al. [6] to filter the A-scans while Short Time Fourier Transform (STFT) was used by Otero et al [7]. After features extraction, Matz et al. [6] applied SVM and Otero et al. [7] applied Clustering analysis to classify the data. For B-scans of welds, texture measure and fuzzy-neural based classifier were used by Shitole et al. [8]. Zahran et al. [9] worked on backwall echo removal, texture analysis and intelligent background removal to segment and classify defects in B-scans of welds. Correia et al. [10] used DWT to de-noise and compress the B-scan of steel samples, then build the Covariance matrix of level 2 decomposition DWT. For C-scans of welds, Polikar et al. [11] and Spanner et al. [12] applied DWT to extract coefficients used to train a Multilayer Perceptron (MLP) which automatically segments and generates classification image. Mandal et al. [13] used similar technique on C-scans of CFRP. In Kieckhofer et al. [14] work on C-scans, it was proposed to work on difference image obtained by subtraction a reference image from the original image. The reference image was generated by filtering the original image. Cornwell et al. [15] proposed an automatic 3D inspection system for 3D ultrasound images of welds. 3D images were reconstructed from raw A-Scans, using CAD models of test specimen. Concerning the evaluation process, a simple threshold on the amplitude of voxels was applied for data containing low noise levels.

As it can be noticed from the above mentioned references, most segmentation work of ultrasonic images is done on B or C scans mainly because these modes are usually available on commercial systems. Very little work is done on the evaluation of three dimensional ultrasonic volumes. This subject is tackled by this paper, where the task is to propose a three dimensional automatic interpretation of ultrasonic reconstructed volume.

At present the development of the Sampling Phased Array (SPA) technique [16], in Fraunhofer IZFP, allows a fast representation of defects at their original positions in the inspected object in 3D space, in addition to a better quality of ultrasound images in terms of signal to noise ratio and higher speed in the inspection process. Procedures like Synthetic Aperture Focusing Technique (SAFT) are integrated. They allow the refocusing of the inspection data sensed in an inspection aperture into a pixel space for imaging. The image visualizing defects offers the possibility to predict their sizes [17]. From here came the idea to complete such inspection system with an automatic evaluation of the inspection results.

This paper is organized as follows: data acquisition is explained in the next section. In the
third section the adopted segmentation approach is described and more illustrated in the corresponding subsections. Afterwards, application of this approach is presented. This paper ends with a conclusion and further propositions for future work.

2 Data acquisition: ultrasound volume

To inspect the specimens, we dispose of a measurement station consisting of a water immersion tank, 3-axes manipulator and 64-channel phased array system capable of multichannel inspection as well as Conventional Phased Array and Sampling Phased Array inspection in contact or immersion technique [16].

![Image](image.png)

Figure 1. (Left) Measurement station with corresponding immersion tank and three axes manipulator, (upper right) a CFRP plate being inspected, using SPA mode, with a 16 elements probe, (lower right) part of the corresponding reconstructed 3D volume.

In figure 1, a Carbon Fibre Reinforced Polymer CFRP plate is inspected using the SPA mode with a sampling speed of 70 mm per second. A 3D-image is reconstructed in real time giving information about presence, depth and dimensions of potential defects. The next step is to implement an automatic procedure to detect and classify those potential defects without prior info about the specimen.

3. Segmentation approach

The basic principle of the presented method is presented in this section and resumed in figure 2. Besides thickness estimation by detection of entrance and backwall echo, the main feature is a reference less inspection, i.e. there is no need for any a priori knowledge of the geometry of the sample. This feature allows evaluating the sample volume for inner defects. First data correction is done on the original ultrasonic volume then noise reduction by means of 2D median filter is applied slice by slice. Afterwards, the entrance and backwall echoes (EE and BWE) are detected and then the internal volume, is extracted from the pre-processed volume. The segmentation is carried out on the internal volume by
applying a threshold on voxels values and then connecting similar voxels to form regions. Each region is characterized by a list of features in order to classify it as defective or not defective (false alarm).

2.2 Data correction

The inspection process is synchronized with data acquisition and image reconstruction. During the inspection, the transducer moves with a specified speed over the surface of the specimen. This speed is relatively high compared with other inspection technique (typically 70 mm per second). Due to this high speed, no signal is received for some points of the sample. This causes the appearance of black voxels with no valid values in the reconstructed volume. The higher the inspection speed, the more black voxels appear in the volume.

It is important to fill these black voxels and to memorize their initial position in the slices space. A method based on a modified median filter is proposed where an NxN window is applied over each slice. If the central pixel in the window is null then it is replaced by the median value of all non null pixels inside the window. The position of the corrected pixel in the slice is saved into a map, which will serve in the classification step afterwards. If the central pixel is not null then it will not be modified.

2.3 Noise reduction

The objective in this step is to enhance the image and improve the signal to noise ratio so that the resultant image is more suitable for the ulterior stages. To smooth the image, currently we chose to apply a quadratic median filter on each slice of the volume. This filter smoothes the image without loss of information about boundaries. Application of another filter like the M3 filter [4] is planed to be investigated later.
2.4 Extraction of Entrance and Backwall echoes

The isolation of the entrance and backwall echoes permits depth localization of defects inside the volume. The backwall echo is the last slice in the requested volume to analyze. Nevertheless in the SPA technique, the inspection depth is manually specified by the expert during the inspection process. For instance for a part of 10 mm depth, the expert choose to inspected 15 mm in depth. In the reconstructed volume, the slices from 11 to 15 mm are not necessary and should be automatically eliminated from the total volume. By detecting the backwall echo, slices after the BWE are not considered.

In case of planar specimen, a method is proposed to automatically detect the EE and BWE. It is based on the calculus of mean value of each slice of the median filtered volume. The entrance echo is characterized by high mean values, while an internal slice has much lower mean value than the EE and the BWE has high mean value as well. Based on this fact, EE is searched between begin and center slices, while BWE is searched between center and end slices.

The extraction of the EE and BWE is critical. In fact defects may exist near the surface or the backwall of the inspected object, therefore if the corresponding slice(s) is (are) considered as entrance or backwall echoes slice (s), then those defects will not be detected.

2.5 Binarization of internal volume

After localizing the EE and BWE, the internal volume is extracted. Next a threshold is applied on the voxel values, dividing between foreground and background. The Otsu method [18] is applied to find a threshold. In fact, the Sahoo study on global thresholding, [19] concluded that Otsu’s method was one of the better threshold selection methods for segmentation process. Otsu’s method uses an exhaustive search to evaluate the criterion for maximizing the between-class variance.

2.6 Connected components analysis

After the previous step, the internal volume is divided between background and foreground. Voxels belonging to the same region are connected to each other. For each voxel 26 neighbors are checked, and connected voxels are grouped into one label (region) with a unique identification number which is also used as grey level for this label. After this step, features are measured to characterize each label.

2.7 Features extraction

Features extraction is the first step required to distinguish the false alarms from the defects. Since during the segmentation process, some small object or structural parts of the reconstructed volume may be considered as potential defect, this step is a starting point to provide information about discontinuities. Features extraction is centered principally around the measurement of geometric properties (area, depth, volume, etc…) and on the intensity characteristics of regions. With this end, a feature selection is carried out to find the best subset of features. In the second step, this subset will be the input of a classification.
method to finally decide about the nature of each suspicious region. This will be done in our future work based on our previous studies [20].

3. Preliminary results

Anisotropic materials such as CFRP are a challenge for any segmentation process of ultrasonic image. In addition, when defects are near the entrance or the back wall, they are hard to detect. All these factors were in mind when we decided to conduct the proposed segmentation process on a generic CFRP specimen with a size (X, Y and Z) of 380x290x14 mm$^3$. The specimen has artificial, weak and strong absorber, defects (inserts) placed close to entrance (1 mm depth), the centre (7 mm) and the back wall (13 mm), see figure 3.

During inspection, a calibration wedge is used to improve the quality of the measured data. It allows for each depth a certain gain to be applied on the measured signals.

Figure 3. CFRP specimen: defects at 1 mm, at 7 mm and at 13 mm depth.

The inspected surface of the specimen is 320x230 mm$^2$. SPA technique revealed the presence of all the defects inside the specimen as it can be seen in figure 4. The reconstructed volume size (X, Y and Z) is 310x265x31 with a voxel size of 1x1x0.5 mm$^3$.

Figure 4. XY views of the inspected CFRP specimen: defects at 1-1.5 mm depth (a) defects at 7 mm depth (b) and (c) Defects at 12.5 mm depth.
After inspection comes the image processing step. First the data correction takes place (see figure 5), and then noise reduction using 3x3 median filter is applied on each slice of the volume.

![Figure 5](image)

Figure 5. (a) Raw XY slice (Z=0), (b) Corrected slice and (c) Map to the positions of the corrected pixels.

Afterwards, entrance and backwall echoes were successfully automatically detected using the proposed method in 2.3, see figure 6. Entrance echo started at Z=0 and ended at Z=1, corresponding to 1 mm thickness. The backwall echo is at Z=27 (at 14 mm depth).

![Figure 6](image)

Figure 6. (a) XZ image, (b) Mean values profile along Z axis: EE is on the left position and BWE is on the right position.

The internal volume starts at Z=2 until Z=26. It is automatically extracted from the global volume, the rest of the processing is only done on the internal volume. Next binarization using Otsu threshold is done (see figure 7). Some results are presented in figure 8. As it can be noticed, artifacts appear near the entrance (Z=2) and backwall slices (Z=26).

![Figure 7](image)

Figure 7. Global histogram of gray values for the internal volume. Otsu threshold is at gray value 3074.
Next step is to group every connected voxels together to form labeled regions in the volume. Figure 9 shows results for the defects inside the volume (Z=13, 14 and 15).

Figure 9. Results of the connected components analysis: labeled regions inside the CFRP specimen.

The last step is to characterize each labeled region by a list of features in order to classify it as defective or false alarm. This step is to be done in future work.
4. Conclusion and perspectives

In this paper, an overview of the preliminary results achieved in our work on the automatic evaluation of three dimensional ultrasonic data is given. The application of the proposed method shows very interesting results. Now the focus is to complete the feature extraction step and to optimize the segmentation process, for instance improve the noise reduction step by better finding a more adapted filtering method. Complex structures are also in our focus, the segmentation of complex structures is one of our future goals. As for the classification process, our work in [20] can be very helpful in finding the efficient subset of features to measure and later in the classification step.

References