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MOTION ESTIMATION OF ULTRASONIC PROBE USING PHASE-CORRELATION

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ABSTRACT

Non-Destructive Evaluation is concerned with developing techniques and methods for the quantitative characterization of materials or structures. The focus of this paper is on its application for flaw detection in steel materials. We compare two ultrasound imaging techniques, namely the Synthetic Aperture Focusing Method (SAFT) and Total Focusing Method (TFM) along with Phase-Correlation, a global motion estimation technique, regarding their performance on motion estimation of the probe. Simulation results show that for high level of noise, the TFM with the proposed motion estimation method worked more satisfactorily than SAFT technique did.

Keywords: TFM, SAFT, NDE, Global Motion Estimation, Phase-Correlation

1. INTRODUCTION

In the last decade, Non-Destructive Evaluation (NDE) field has seen a significantly increase in use of ultrasonic arrays to carry out tests. An NDE inspection using ultrasonic arrays consists of positioning the array on the surface of the test structure and either couple it directly or through some intervening coupling medium [4]. The ultrasonic transducer is normally made of a piezoelectric material which converts the electrical pulses into mechanical pulses that then propagate as a beam of ultrasound into the evaluated part [12]. Therefore, they allow the internal structures of engineering components to be even more realistically and efficiently visualized [6].

The data are gathered using the Full Matrix Capture (FMC) acquisition, where every transmitter-receiver pair is used to obtain an a-scan signal. In the post-processing operation, imaging algorithms such as the synthetic aperture focusing technique (SAFT) [9], and the total focusing method (TFM), [1] are used. TFM has been demonstrated more robust for higher noise levels [6]. Both algorithms tend to produce high resolution images, but their resolution is diffraction limited. An important issue related to ultrasound images reconstruction is to estimate the motion of ultrasound probe, because unwanted and unsettled moves caused by the manipulator of ultrasound probe result in blur, noise, and aliasing effects in a reconstructed image. In addition, using an estimated physical motion through the sub-pixel movement, the use of encoder connected to probe becomes dispensable. We consider that the manipulator of the ultrasound probe has no encoder, which means the location of the transducer is not available. If we get an accurate motion estimation, it is possible to reconstruct a higher resolution image fusing the data from different probe positions.

Nowadays, there are several motion estimation algorithms, termed Global Motion Estimation (GME). They are able to determine motion vectors that describe the sub-pixel displacement between two images. In [8], it is presented a motion estimation from video images using phase correlation and linear optimization. In [5], it is introduced application of unnormalized and Phase-Correlation techniques on infrared images. In this present work, we look into translational motion. The main aim of this paper is to compare two scanning imaging techniques that are capable of dealing with estimating the motion of ultrasonic probe.

This paper is organized as follows. in Section 2, we describe the main steps of the algorithm. In Section 3, the Phase-Correlation method and outline its important properties. In Section 4, we present the experiment setup of the simulations. Section 5 provides the experimental results. Finally, in Section 6 some concluding remarks are provided.

2. ALAGORITHM DETAILS

First, we establish the procedures to estimate the displacement of the ultrasonic probe. The region of interest (ROI) was set according to the position of the ultrasound probe. The TFM and SAFT algorithms were used to reconstruct images from each FMC data acquisition. Thus, two images were obtained for each data acquisition. Then, the Phase-Correlation algorithm was applied to estimate the sub-pixel displacement between the image 1 and the image 2. To calculate the real motion of the probe, it is necessary to convert the sup-pixel displacement into physical displacement. Finally, it is possible to reconstruct new images using the estimated motion of the probe. Thus, we can summarize these operation steps as:

1. Collect data at different positions;
2. Reconstruct images for each position individually, using TFM and SAFT;
3. Estimate the sub-pixel displacement between the two images;
4. Convert the sub-pixel displacement into millimeter displacement;
5. Reconstruct new TFM and SAFT images using the motion information.

In this work, we focus on the steps 1 through 4.

3. PHASE-CORRELATION METHOD

We chose a GME algorithm termed Phase-Correlation to obtain an accurate estimation of motion of the ultrasound transducer with sub-pixel accuracy and able to estimate translation motion. This method is based on the Fourier Transform shift property, which states that a shift in the coordinate frames of two functions is transformed in the Fourier domain as linear phase differences. The horizontal and vertical displacement can be found calculating the inverse Fourier transform of cross-power spectrum of both images, which would lead to a unit impulse centred at relative shift. Thus, we find the arguments of the maxima of this function, which gives $\Delta\, \boldsymbol{x}$ and $\Delta\, \boldsymbol{y}$ represent the horizontal displacement and the vertical displacement, respectively [7]. The conversion of the sub-pixel displacement to millimeter displacement is achieved multiplying the pixel-width by estimated horizontal displacement.

In the literature, some works can be found that approach this method and give important contribution to application of Phase-Correlation in motion estimation. In [11], it is provided some comparisons and evaluations for sub-pixel motion estimation using Phase-Correlation. In [2], it is proposed a novel image registration method based on phase correlation using low-rank matrix factorization with mixture of Gaussian. In [3], Douini et al. present a new sub-pixel image registration that aligns a pair of translated images using Phase-Correlation. Mohamed et al. [10] introduce a sub-pixel accuracy analysis of Phase-Correlation shift measurement methods.

4. EXEPERIMENT SETUP

In order to verify the algorithm experimentally, two inspection simulations were performed to generate data using the ultrasonic module of the CIVA NDT® simulation software. The design of the specimen consists of an 80x24x60 mm Aluminium 2024 block with longitudinal wave velocity equal to 6370 m/s. A side drilled hole was place along Y axis on the centre of the block. The probe type chosen was with contact and the crystal has a linear phased array of 32 elements with width of 0.7 mm each, gap between elements of 0.1 mm. Two FMC scans were performed by positioning the transducer over the specimen at two different positions. First the probe was positioned at the reference point, where x=40 mm and y=12 mm that corresponds to the middle of the specimen. Then, the probe was moved from the reference point 4 mm to the right, which corresponds to coordinates x=44 mm and y=12 mm. As a result, we acquired two sets of FMC data to obtain two images at different instants, thus we have a data acquisition at first position and another data acquisition at second position as Figure 1-(a)-(d) shows.

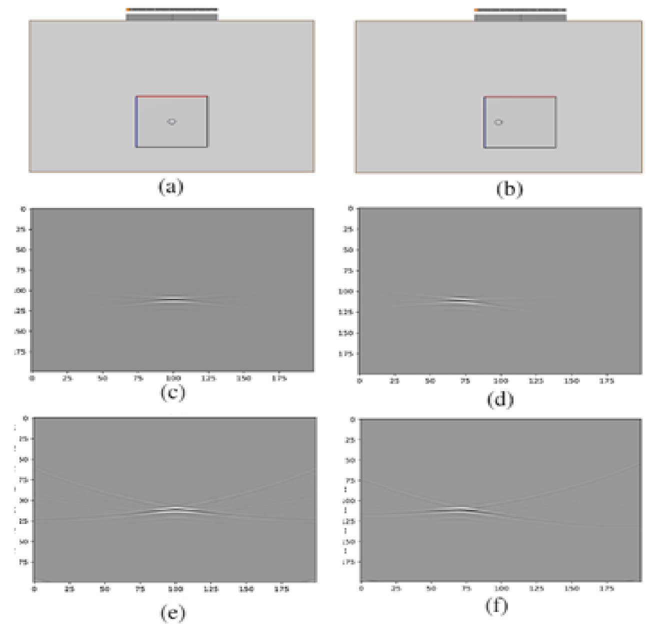

FIGURE 1: a) Transducer at position x_1=40 mm. b) Transducer at position x_2=44 mm. c) Reconstructed image at position x_1 using TFM. d) Reconstructed image at position x_2 using TFM. e) Reconstructed image at position x_1 using SAFT. f) Reconstructed image at position x_2 using SAFT.

5. RESULTS AND DISCUSSION

The Phase-Correlation algorithm was tested using on reconstructed images with TFM and SAFT techniques. We calculated, the experimental mean, variance and Mean Absolute Error - (MAE) of horizontal motion estimation $\Delta\, \boldsymbol{x}$ for 1000 iterations. The Table 1 shows the results of motion estimation of the ultrasound probe, which the ultrasound images were reconstructed using TFM. For this test, we considered a true displacement of 4 mm along axis x as shown in Figure 1-(b).

TABLE 1. Simulation Results using TFM for a real displacement of 4 mm. This table shows the variation of Mean, Variance and Mean Absolute Error of $\Delta\, \boldsymbol{x}$ with SNR.

SNR	Mean $\Delta\, \boldsymbol{x}$ (mm)	Variance $\Delta\, \boldsymbol{x}$ (mm)	Error $\Delta\, \boldsymbol{x}$ (mm)
5	3.6332	0.0206	0.3668
10	3.6132	0.0116	0.3867
15	3.5926	0.0060	0.4074
20	3.5818	0.0031	0.4181
25	3.5794	0.0020	0.4205
30	3.5724	0.0027	0.4275

This simulation has shown that the TFM has a good performance for low and high levels of SNR. In other words, it seems to have robustness to noise when the Phase-Correlation is performed to estimate the motion of the transducer along X axis. As matter of fact, it implies that for a very noisy environment such as ultrasonic inspection of submarine pipelines, TFM is a better choice. Although the Mean Error slightly increases when the SNR rises, the Variance decreases considerably. We suppose that this technique may consider that a displacement between the two ultrasound images is not so significant for a low level of noise.

The results of simulation using SAFT technique are shown in Table 2. It has an unsatisfactory performance in an SNR below 10dB. As we can see, the mean absolute error increases greatly as the SNR decreases. This shows that, when Phase-Correlation method is performed to estimate the motion of the probe, SAFT may not be very efficient for high levels of noise. However, its Mean Absolute Error decreases while the SNR increases.

TABLE 2. Simulation Results using SAFT for a real displacement of 4 mm. This table shows the variation of Mean, Variance and Mean Absolute Error of $\Delta\, \boldsymbol{x}$ with SNR.

SNR	Mean $\Delta\, \boldsymbol{x}$ (mm)	Variance $\Delta\, \boldsymbol{x}$ (mm)	Error $\Delta\, \boldsymbol{x}$ (mm)
5	0.6098	48.9409	3.3901
10	3.8110	0.6285	0.1889
15	3.8383	0.0122	0.1616
20	3.8405	0.0068	0.1594
25	3.8549	0.0040	0.1450
30	3.8768	0.0031	0.1231

Probably, this is because the SAFT considers that the sub-pixel displacement between two ultrasound images is more perceivable. Despite of that, its variance is higher comparing to TFM variance.

4. CONCLUSION

This paper proposed a motion estimation of ultrasonic probe based on Phase-Correlation algorithm for the ultrasound image reconstruction techniques TFM and SAFT. We estimated the estimation of the probe by collecting ultrasound data at two different positions, then TFM and SAFT algorithms were applied to reconstruct images singly for each position. Thereafter, we obtained the sub-pixel displacement between the reconstructed images at first position and second position and converted it into millimeter displacement. The obtained results show that for higher noise levels, the TFM reconstruction technique demonstrated more effectiveness than the SAFT technique when we used the phase correlation algorithm to enhance the estimation of the ultrasonic probe motion. Future works concern deeper analysis of our method on specimens containing other types of flaws. In addition, we intend to carry out some studies on other global motion estimation algorithm and evaluate their performances on real non-destructive testing data.

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