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IMAGE-BASED ULTRASOUND SPEED ESTIMATION FOR NDT IN HOMOGENEOUS MEDIA

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ABSTRACT

In Non-Destructive Testing (NDT), ultrasound imaging is a useful tool for detecting flaws or measuring corrosion in metal pipes. The use of phased arrays is becoming a standard in NDT and with it, the use of post-processing focusing techniques. Such techniques make use of parameters as distance between transducer elements, times of arrival and sound speed propagation to produce focused images. This work proposes a method to estimate one of these parameters, the sound speed, by measuring the sharpness of the reconstructed image. The results, obtained in both simulated and real scenarios, indicate that it is possible to obtain estimates with low error. These results could lead to a method of recovering local sound speeds in non-homogeneous media.

Keywords: NDT, Ultrasound, Beamforming, Sensor Array, Parameter Estimation

1. INTRODUCTION

The use of phased-arrays for ultrasonic imaging has become a standard for industrial Non-Destructive Testing (NDT) for its capabilities of beam focusing and steering and electronic scanning. The conventional use of phased-arrays consists in applying delay laws at the transmission in order to focus the beam to a single point. This process is repeated for each point imaged. Another way of focusing is by emitting several unfocused waves and post-processing the received data in order to obtain a focused image using algorithms such as the Synthetic Aperture Focusing Technique (SAFT) [1]. This technique depends on the knowledge of the wave propagation speed on the specimen. In the case of a mismatch between the assumed and actual speeds, the recovered image will have distortions and appear blurred, making it harder to detect flaws.

Generally, the sound speed is calibrated using a specimen of the same material with known geometry, but that is not always possible. In the case of submarine inspections, the speed can only be calibrated before the inspection and so it does not account for the differences in temperature and pressure.

When there is no information available on the geometry of the specimen, the distortion on reconstructed images may be used to determine the actual propagation speed in the specimen. By defining a metric for image quality, it is possible to search for the estimate speed that maximizes, or minimizes, this metric and thus find an estimate closer to the actual speed. In this sense, the wave speed can be used as a focusing parameter that can be tuned based on visual assessment of image sharpness. This process consists in a grid search to find the extremum of a given metric or focus function. This concept was applied on medical ultrasonic imaging [2, 3, 4] and photo-acoustics imaging [5, 6, 7].

2. AUTOFOCUS APPROACH TO SPEED ESTIMATION

In this work, we intend to study the use of different functions to obtain an estimation of sound speed in NDT scenarios. For this purpose, we analyze the use of the following functions: Brenner Gradient, Tenenbaum Gradient, normalized variance, contrast and the Spectral and Spatial Sharpness (S3) metric [5, 8, 9].

The gradient functions are based on 2D convolution between the image and a kernel. For the Brenner Gradient the kernel is defined by

$$g_{Brenner} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} , \tag{1}$$

while the kernel for the Tenenbaum Gradient is defined by

$$g_{Tenenbaum} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} . \tag{2}$$

The normalized variance is defined as

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$$NVar = \frac{1}{\mu}\text{var}(I), \tag{3}$$

in which I is the image array, μ is the mean value of *I* and var(*I*) denotes the variance of *I*.

The contrast function can be calculated as

$$Contrast = \frac{\frac{1}{N}\sum I^2}{\mu^2}. \tag{4}$$

The S3 metric is a block-based algorithm that uses spectral and spatial properties of an image and combines them with a weighted geometric mean to quantify the local sharpness of an image. For details in this algorithm refer to [9].

In order to find the extremum of the metrics, we adopted a grid search scheme, mainly because of the number of local extrema produced by the metrics in the interval evaluated. The procedure is as follows:

1. Define the minimum and maximum speeds, C_{L_Min} and C_{L_Max};
2. Define the step size ΔC_L;
3. Starting with n=0, define $C_{L\_Est} = C_{L\_Min}+n\,\Delta C_L$
4. Apply the focusing technique (SAFT) considering the speed as C_{L_Est};
5. Evaluate Focus Function on the reconstructed image;
6. Iterate n and repeat from step 4.

3. RESULTS AND DISCUSSION

To verify the effectiveness of the autofocus approach to speed estimation in NDT we conducted experiments on both simulated and experimental data. The use of simulated data is a practical way to verify our method for a scenario where the only variable changing is the sound speed.

Using the NDT simulation software CIVA, we simulated acquisitions on a homogeneous block with varying longitudinal wave speeds. The simulated specimen has dimensions 80x60x24mm and an SDH of 1mm radius positioned 10mm below the center of the larger face of the block. Around the SDH is located our region of interest (ROI), as illustrated in Figure 1. The ROI excludes the bottoms reflections and focuses only in the simpler problem of imaging the flaw.

For reconstructing the images, we used the ω-k SAFT [1], an implementation of SAFT in the frequency-domain that is much faster than its time-domain counterpart.

Using a grid search in the range [C_L-300, C_L+400] with a step of 1m/s and C_L assuming the values: 4000, 5000, 5900 and 6300m/s, we reconstructed the images with ω-k SAFT. The minimum value of each autofocus function and simulated speeds are summarized in Table 1. The contrast metric presented the lowest errors while the S3 metric the highest error.

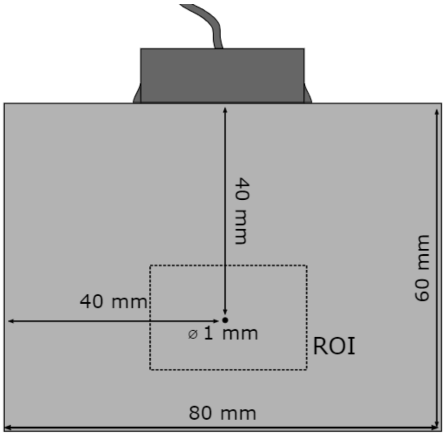

Figure 1- Specimen used for both simulation and experiments. The actual specimen is made in aluminum and has a calibrated speed of 6319m/s.

Table 1- Estimated values of speed for simulated data. Different scenarios considered different sound speeds for the solid block of Figure 1.

	Estimated C_L (m/s)			
Actual C_L	4000	5000	5900	6300
Brenner	4016	5020	5922	6323
Tenenbaum	3920	4920	5806	6200
Variance	4017	5019	5921	6321
Contrast	**3986**	**4999**	**5895**	**6293**
S3	4125	5131	5941	6317

To further verify the proposed method, data was acquired using a M2M Multix++ and a phased array probe of 64 elements and central frequency of 5MHz. We used an aluminum block exactly as illustrated in Figure 1. The block was immersed in water and the probe was placed in direct contact with it.

First, we measured the echoes from the bottom of the specimen to find the sound speed. Our measurements resulted in a speed of 6319.5m/s. Then we defined the ROI just as it was defined for the simulated experiments and applied the autofocus functions to images reconstructed in the interval [6000, 6700] with a grid resolution of 1m/s. The curves for the autofocus functions are shown in Figure 2. The minima of these curves are summarized in Table 2. The estimated speeds are very similar and present an error of less than 1%, except for the Tenenbaum gradient function that estimates a speed that represents an error of almost 5%. These estimates are lower than the estimates for the simulated specimen with sound speed of 6300m/s, shown in Table 1.

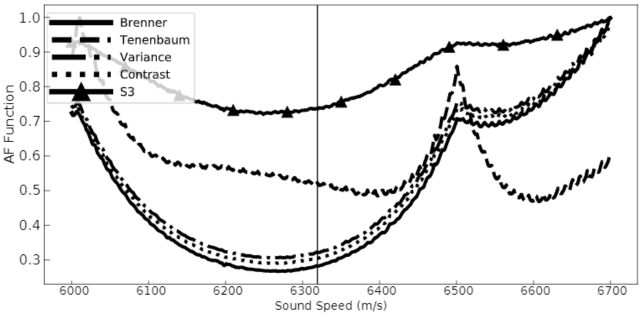

Figure 2 – The curves shown the focus functions evaluated on the images reconstructed considering different sound speeds. Only the Tenenbaum curve shows very different pattern.

Table 2 – Estimated values for sound speed in an aluminum block.

Function	Estimated Speed (m/s)
Brenner	**6271**
Tenenbaum	6620
Variance	6258
Contrast	6258
S3	6263

4. CONCLUSION

In NDT, a mismatch in assumed sound speed or some degree of non-homogeneity in the material can be the cause of ill-reconstructed images. Images contaminated with blur and artifacts can difficult the detection of flaws or the determination the position and dimensions of flaws. A mismatch can be reduced by applying a calibration procedure. Given the difficulty of such calibration procedure in scenarios such as a submarine inspection, we proposed a method to estimate the sound speed without in a material without specific knowledge of its geometry.

The proposed method intends to estimate sound speed only by applying focusing techniques in a post-processing way. The method consists in reconstructing images with focusing techniques, such as the ω-k SAFT, for different assumed sound speeds and evaluating a focus function for each image. Searching the speed that minimizes, or maximizes, the focus function gives the actual sound speed in the medium, or an average value for non-homogeneous media.

In the tested scenario, the results presented show that the method can make estimates with errors smaller than 1%. The results also show that focus functions present in the literature have very different degrees of usefulness, for example, the Brenner gradient is simpler than the Tenenbaum and still has better performance. Similarly, the S3 function is the most complex used and has poor results compared to the contrast function.

Improvements to the method, like the use of algorithms such as TFM, that uses the most data available from a phased array, require that we drop the time requirements. The grid search scheme could be replaced by a search method, such as the golden section search, for intervals where there are no local extrema. Further studies intend to tackle these possible optimizations.

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