

SAFT Implementation Test

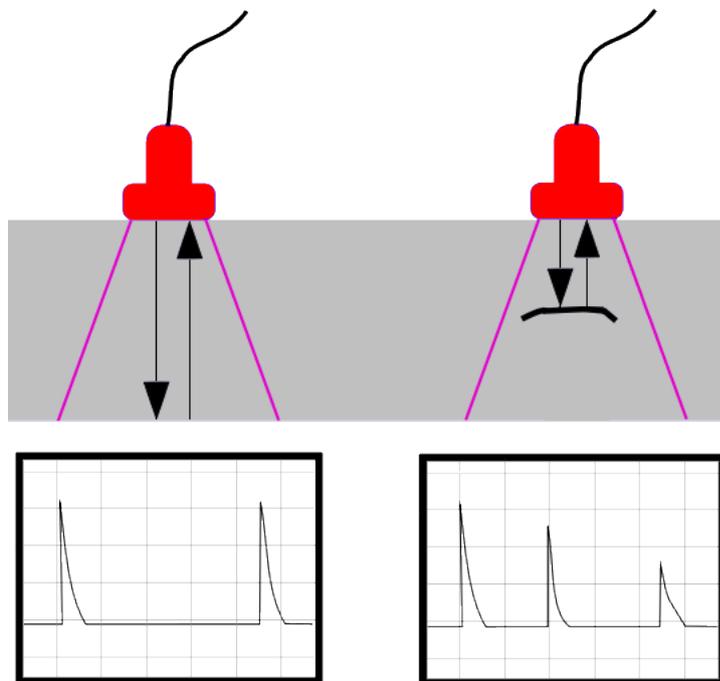
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1 Introduction

In the field of Non-Destructive Testing (NDT), ultrasound imaging is among the most common techniques to extract information about an object. This test consists of a transducer - usually constructed using piezoelectric crystals - emitting ultrasound pulses and recording the echoes created by the wave propagation in the object. Since the wave is affected by the materials in its travel path, these echoes contain information about the subsurface structures of the object, especially the distance to these structures given by the travel time. A basic diagram illustrating this principle is shown in Figure 1.

Figure 1: Ultrasound testing example. The red elements are transducers, the grey area is the object, and the black line is an internal crack/defect. Below is the recorded wave for each transducer. On the left, one can see two pulses: the first is the emission, and the second is the wave reflected by the bottom of the object. On the right, there are 3 pulses: the first and last are also emission and bottom reflection, respectively. The middle one is caused by the sound wave reflecting from the crack. These wave plots are called A-Scans.



Source: Wermac, 2023

It is important to highlight a phenomenon intrinsic to acoustic waves: they travel in all directions at the same time. This implies that the time between pulse emission and echo reception does not pinpoint the reflecting structure position but rather its distance to the source. There is a semi-circle of equidistant points where the reflector

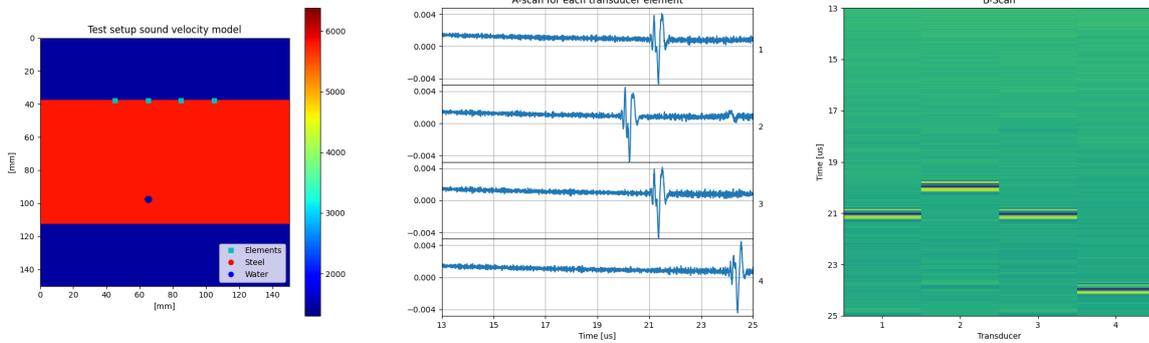
can be located, so measurements from multiple positions are needed to obtain its precise location.

2 Transducer arrays

In the diagram shown in Figure 1, each transducer is single-element, i.e., only one crystal (called an element) is present. However, there are transducers with a large number of elements, usually in a row. These are called linear transducer arrays and allow, for example, emitting pulses from different angles or recording echoes received in different positions than the emitting one. Therefore, a single transducer can measure wave propagation from multiple angles, which can help obtain more precise reflector positions, as explained in Section 1.

Since the result from a single-element test is one A-Scan, a test with a transducer array containing N elements will produce N A-scans. To visualize these scans, instead of amplitude plots, it is easier to show them as an image, where each column is the A-scan from one element, the rows are the time axis, and the wave amplitude is represented by color. This visualization is called a B-Scan. Figure 2 shows a specimen and the transducer locations, the A-Scan from each transducer, and the B-Scan constructed from the A-Scans. Since there is a hole in the steel specimen at the position (65,97), echoes are generated when the waves emitted are reflected at this point. The longer the distance between the reflector - in this case, the hole - and the transducer element, the later the echo arrives.

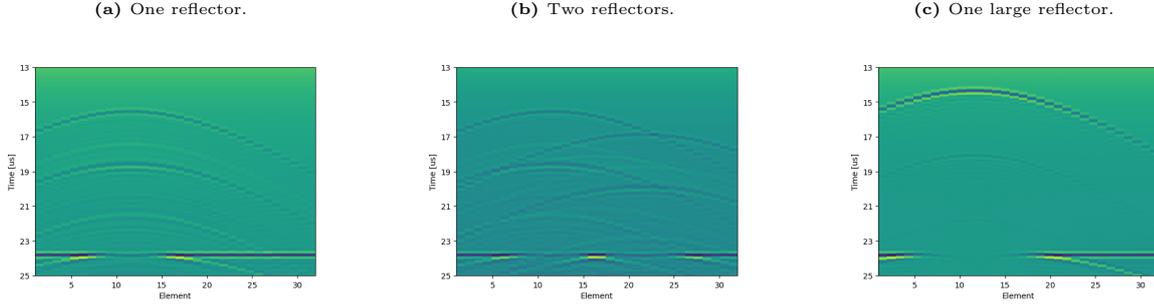
Figure 2: B-scan construction. On the left is the specimen, on the center are 4 A-scans from 4 elements in a test done with an array, and on the right is the B-scan constructed from these A-scans. Each column is one of the A-scans, in order, and the amplitude can be interpreted through the color scale.



The example in Figure 2 has only 4 elements to facilitate visualization, but usually, the transducers have between 32 and 64 elements. In Figure 3, examples of more realistic settings are shown.

Although it is possible for a trained operator to interpret the B-Scan in order to obtain information about the sub-surface structures, it is not an image *per se*, only a visualization of the pulse echoes. To construct an image, more advanced processing is necessary.

Figure 3: B-scans examples. In 3a we have a similar setup to the example in Figure 2, but with more elements. In 3a, there are two reflectors. It is important to note a large number of additional echoes are present due to multiple reflections between the reflectors. In 3c, we have only one reflector again, but a larger one. Note how the number of echoes diminished, and the shadow at the bottom increased. The straight line in all figures is the reflection caused by the bottom of the specimen.



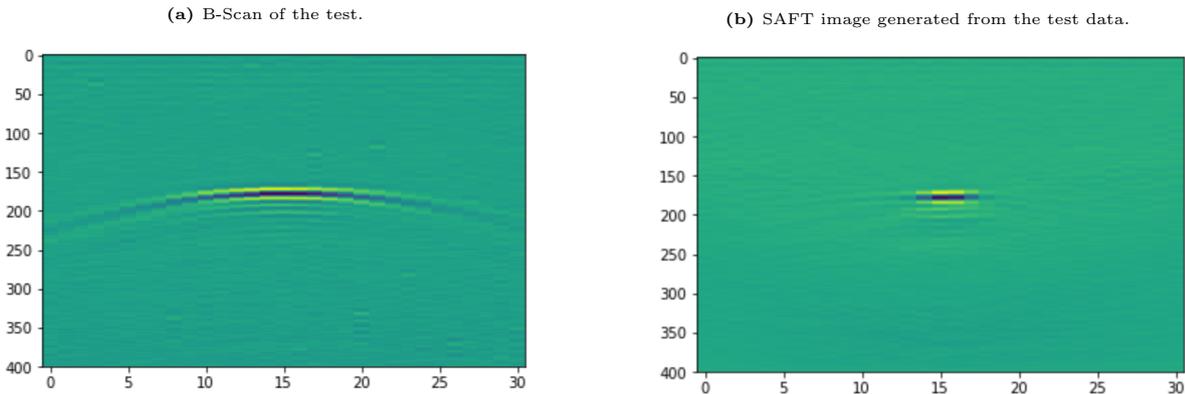
3 Image generation

One method to construct images from wave recordings is called Synthetic Aperture Focusing Technique (SAFT). The gist of this algorithm is to, for each position in space inside a Region of Interest (ROI), calculate the time at which a hypothetical reflector in this position would generate an echo in each A-Scan.

To obtain these times, one must only calculate the travel time of the sound wave in the inspected material from the transducer position to the position of the ROI pixel. Therefore, in addition to the wave recordings, the algorithm needs the transducer positions and the sound velocity in the material from which the specimen is made, as well as the discretization parameters used to record the sound waves.

The final step is, for every position in the ROI, sum the values of each recording at their respective estimated time of echo arrival, and use this sum as the pixel brightness in the image. The resulting images are shown in Figure 4. More details can be found in [1], and more examples are shown in [2], Figures 2 and 5.

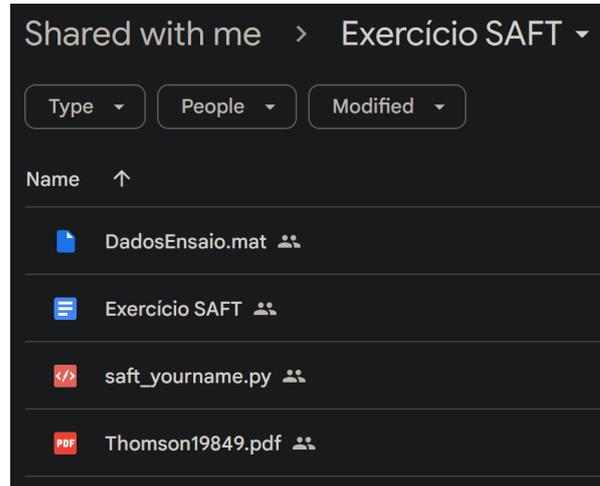
Figure 4: SAFT example. This test was done on a solid block of aluminum, with one side drilled hole (SDH). In Figure 4a one can see the same arc pattern shown in Figures 2 and 3a. When the SAFT algorithm is applied, we get Figure 4b, which better represents the internal structure of the specimen.



4 Assignment

The assignment consists in implementing the SAFT algorithm in Python. The test recordings, as well as the code template with data import and test parameters, can be found in [this folder](#), named respectively as **DadosEnsaio.mat** and **saft_yourname.py**, as shown in Figure 5. The data corresponds to the one used in Figure 4, so the result of your implementation should like the one in Figure 4b.

Figure 5: Folder containing the necessary data for the assignment, as well as the code template.



References

- [1] R. Thomson, "Transverse and longitudinal resolution of the synthetic aperture focusing technique," *Ultrasonics*, vol. 22, no. 1, pp. 9–15, 1984, ISSN: 0041-624X. DOI: [https://doi.org/10.1016/0041-624X\(84\)90055-6](https://doi.org/10.1016/0041-624X(84)90055-6). [Online]. Available: <https://www.sciencedirect.com/science/article/pii/0041624X84900556>.
- [2] G. A. Guarneri, D. R. Pipa, F. N. Junior, L. V. R. De Arruda, and M. V. W. Zibetti, "A sparse reconstruction algorithm for ultrasonic images in nondestructive testing," *Sensors*, vol. 15, no. 4, pp. 9324–9343, 2015, ISSN: 1424-8220. DOI: 10.3390/s150409324. [Online]. Available: <https://www.mdpi.com/1424-8220/15/4/9324>.