**46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA**

QNDE2019-1234

DATA RECONSTRUCTION FOR SPARSE SCANS AND ARRAYS

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ABSTRACT

Using Matrix Phased Probes and manipulator steered scans allow to get best data basis for synthetic aperture focusing technique (SAFT) or similar total focusing methods (TFM). The drawbacks are the high amount concerning the data volume and high costs of the hardware capable of recording many signals at the same time.

This paper explores how well data can be reconstructed in a sparsely sampled data sets where the sampling theorem is not fulfilled. The objective is to quantify the degradation of an image due to sparse sampling. For future array design, this insight helps to make a better trade-off between array aperture and sampling density.

We follow two strategies to reach the goal. The first one is to optimize the geometric distribution of the matrix elements and/or the scan area, and the second is the reconstruction of omitted signals e.g. to increase the quality of a subsequent imaging.

Keywords: ultrasonic testing, matrix array, sparse sampling, signal reconstruction, imaging

1. INTRODUCTION

Matrix phased array probes becoming more and more interesting for ultrasonic testing applications with a view to use echo signals for 3D-imaging. The main drawbacks, using probes with a very large number of transducer elements where each needs to be connected and electrical driven. Especially a high number of receiving canals is a significant cost factor.

In some phased array systems, the number of simultaneous active elements is limited to a certain number, e.g. 2^n, often 32 or 64 in the present situation.

Matrix arrays designed for extended functionality usually have more than 64 elements. Typical arrangements are square matrices. Those setups do not allow to run the probe with all elements active which may cause a change in the directivity pattern of the resulting sound beam. In comparison with the full array the sound field of a sparse array is basically the same with respect to the focal region, while the sensitivity is reduced and the amplitudes of parasitic speckle-like side lobes increase significantly. This is also valid for very large matrix arrays with only a subset of elements in a contiguous region active.

Sound field criteria are appraised, which are important for non-destructive testing results, for imaging and the consequences in relation to the system setup. To study these influences we use semi-analytical simulation tools and measurements. It is expedient to choose proper geometry conditions in sparse array according to focal area/flaw area and the technical boundary conditions. That is the first strategy. In [1] we already discussed the properties of sparse arrays under special conditions of a hardware able to drive only a quarter of the total number of elements.

The second strategy is to synthesize respectively to reconstruct data in order to replace omitted signals if the spatial sampling criterion is not met. A data interpolation approach was introduced [2,3], to reconstruct spatially aliased data. This approach deploys a combination of a focusing/imaging step with an iterative thresholding. The underlying idea is that after focusing the wave field is condensed in a small region. The aliasing noise due to sparse sampling is spread throughout the domain. By apply a threshold, the aliasing noise is removed. First zeroes are placed at the locations of missing data. The algorithm can then be summarized in a number of simple steps:

- Applying focusing step;
- Threshold data;
- Undo focusing;
- Place original data at measured array locations.

The threshold is lowered after each iteration. The threshold selection is an important step, this needs to be chosen such that no significant aliasing noise leaks into the image.

2. ECHO MEASUREMENT AND SIMULATION

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FIGURE 1a shows the basic measurement setup. To analyze the echo signals the elements for transmitting and receiving can be chosen free for all combinations but sequential measured or partially in groups up to 32 elements. All additional combinations can be calculated by subsequent calculations.

FIGURE 1b shows the measured echo height of the TR-signals of a 10 MHz 11x11 elements matrix array in dependence of the position of the receiving element. Transmitter is always the middle element. The pitch is 0.91 mm in each direction and the reflector is a 2 mm flat bottom hole.

FIGURE 1c shows the simulation result using the same parameters referred for figure 2.

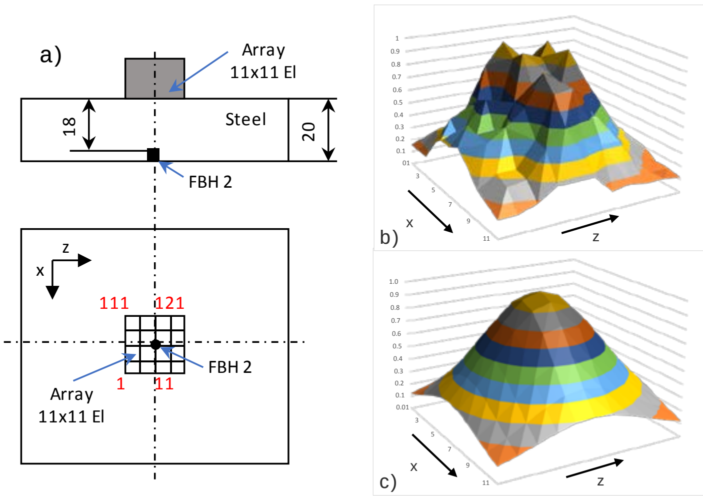
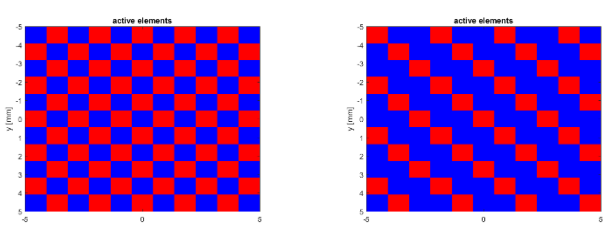


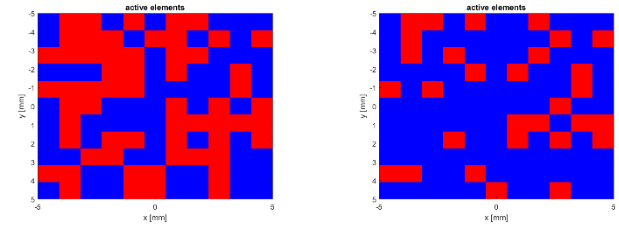
FIGURE 1 a) BASIC MEASUREMENT SETUP, b) MEASURED C-SCAN, c) SIMULATED C-SCAN

3. Data reconstruction and imaging

Two different scenario's will be evaluated, using a regular sampling and using a random sampling (see FIGURE 2). The picture gives an overview which elements are active in the array, the elements shown in red are active for receiving signals. Only one element is used to transmit. In case of a regular sampling one out of a number of elements will be active. Two scenarios are shown here, one where every second element is active (50% active element) and one where every fourth element is active (25% active element). For the random case a percentage of all the element will be active, here 50% and 25% of the elements is used.



a) **b)**



c) **d)**

FIGURE 2 DATA REDUCTION, a) 1 OF 2 REGULAR SAMPLING, b) 1 OF 4 REGULAR SAMPLING, c) 50% OF ALL ELEMENTS USING RANDOM SAMPLING, d) 25% OF ALL ELEMENTS USING RANDOM SAMPLING.

The data is reconstructed using the algorithm described above. FIGURE 4 shows for all four cases the complete dataset and the reconstructed data next to each other. All 121 signals from the matrix array are shown next to each other. The vertical axis indicates depth in millimeter. The indication at 18 mm is the flat bottom hole and the back wall is shown at 20 mm.

In the two cases where 50% of the elements are used, the reconstruction results look very similar as far as the signals are concerned. The noise is the data (seen between elements 40 and 65) is not fully reconstructed because this is not caused by diffracted waves from the medium. This noise is probably due to surface waves at interface between matrix transducer and steel. Comparing the two cases where 25% of the element is used, it is clear that the regular sampling performs less than the random sampling. Particularly the echo from flat bottom hole is less well reconstructed. The random sampling still gives quite acceptable result, only the reconstruction of signals at the edges of the array is not as good. On the other hand quite a bit of noise is removed as well.

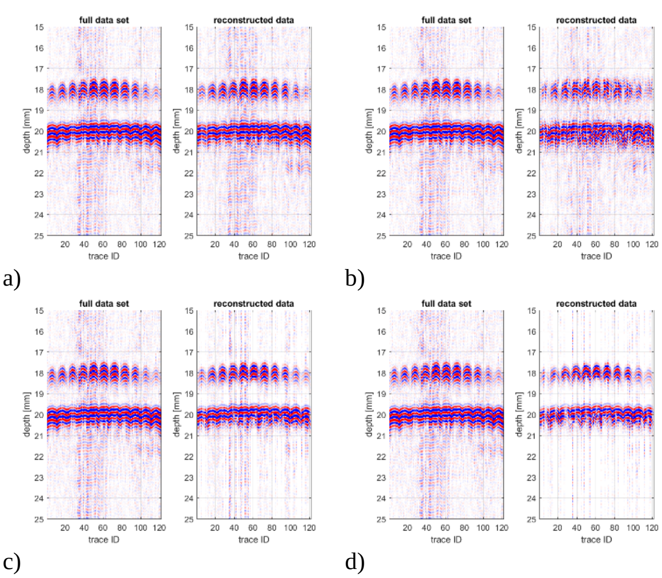
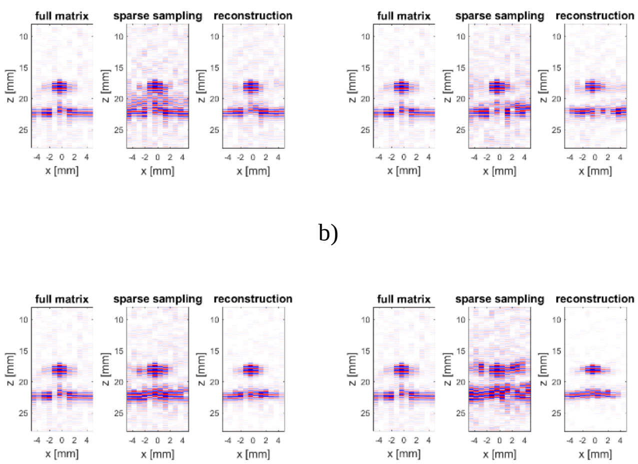


FIGURE 3 COMPARISON BETWEEN ORIGNAL DATA AND RECONSTRUCTED DATA a) 1 OF 2 REGULAR SAMPLING, b) 1 OF 4 REGULAR SAMPLING, c) 50% OF ALL ELEMENTS USING RANDOM SAMPLING, d) 25% OF ALL ELEMENTS USING RANDOM SAMPLING.

Comparing raw signals only might not provide the full picture regarding the performance of sparse sampling and data reconstruction techniques. In many cases, imaging algorithms (SAFT, TFM) will be applied to process. For comparison images are shown in FIGURE 4 for three cases:

- using all 121 signals;
- using only sparsely sample data;
- using reconstructed sparsely sample data.

It is clear that the sparse sampling produces significantly degraded images. The images using the reconstructed data are still quite acceptable. Surprisingly, the images using random sampling contain less noise than the image using the original data. Even a 25% data collection reduction leads to a nice image.



a) b)

c) d)

FIGURE 4 IMAGING OF FULL MATRIX DATA, SPARSE DATA AND RECONSTRUCTED DATA FOR a) 1 OF 2 REGULAR SAMPLING, b) 1 OF 4 REGULAR SAMPLING, c) 50% OF ALL ELEMENTS USING RANDOM SAMPLING, d) 25% OF ALL ELEMENTS USING RANDOM SAMPLING.

These results indicate that data reconstruction techniques are quite powerful. In this example we demonstrated that collecting signals from only 25% of all available elements still gives acceptable images. It obviously does not make sense to only use 25% of the available channels of an acquisition system, but what this demonstrates that it should be possible to use matrix arrays with twice the current aperture (four times as many elements). A twice as large aperture will significantly enhance the resolution in the image.

4. CONCLUSION

When only a subset of elements can be used during a single acquisition, different strategies may be applied to collect or to reconstruct enough data for rebuilding the missing information from the echo signal.

How well data can be reconstructed in a sparsely sampled data sets where the sampling theorem is not fulfilled, that is the exploration of this paper.

Therefore two different approaches using signal processing and smart element selection have been tested by simulation and measurements on a scenario using 121 element 11x11 matrix array with 10 MHz. Detailed results will be presented in the talk.

This approach aims at maximizing the aperture for image resolution, while constraining the level of artifact due to sparsity in spatial sampling.

REFERENCES

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