PREELIMINARY RESULTS: COMPARISON OF DIFFERENT SCHEMES OF SYNTHETIC APERTURE TECHNIQUE IN ULTRASONIC IMAGING

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Abstract: The Synthetic Aperture (SA) methods are widespread and successfully used in radar technology, as well as in the sonar systems. The advantages of high framerate and its relatively good resolution in the whole area of scanning, make this technique an object of interest in medical imaging methods such as ultrasonography (US).

This paper describes the possible usage of the SA method in ultrasound imaging. The introduction to the principles of the SA technique in ultrasonography is presented.

The measurements of different SA schemes were conducted using the set-up consisting of the research ultrasonograph module, the PC and the special wire phantom. The results for different schemes of image reconstruction are presented. Particularly the Synthetic Transmit Aperture (STA) technique was concerned. Results of the STA method are discussed in this paper.

INTRODUCTION

The idea of Synthetic Aperture (SA) in radar technique reaches the early fifties. Fast progress in electronic and signal processing made possible to build the first SA radar in about 1970 [1]. Since then the rapid growth of this method is observed in a broad spectrum of applications: from earth observing satellites, airborne radar to hydroacoustic issues as sonars. Recently, it is used in ultrasonic imaging. In classical methods the image is usually reconstructed line by line from the RF signal for each line. The main idea behind Synthetic Aperture method is to reconstruct image as a sum of low quality images reconstructed for each emission. This method allows for the dynamic focusing while the transmitting and receiving is performed. The image resolution is as good in full depth of scanning as in the classical beamforming in its focal point. It makes the SA images more complex without need of making additional emissions. Lower number of emissions potentially enables obtaining a higher value of framerate. More information on SA techniques is presented in [1, 2].

The root for this research is the project being conducted in the Institute of Fundamental Technological Research, Polish Academy of Science. The goal of the project is to build an advanced ultrasonograph which can perform the imaging based on the SA technique. Hence, the detailed analysis of many aspects related to building this device should be performed. One of fundamental issues is the way how the data is acquired. The transmitting and receiving schemes and further signal processing are crucial problems. The SA technique is successfully applied in transient elastography approach, called Supersonic Shear Imaging [3, 4, 5] as well as the commercial ultrasonic scanner ZONARE z.one *ultra* SmartCart System. The advantages of the method, i.e. its high framerate and good resolution, gave the basis for the detailed study in order to apply it in constructed device.

1. SYNTHETIC APERTURE IN ULTRASONIC IMAGING

Contrary to the SA method used in radar technique, there is no movement of transducer over scanned area in ultrasonic application. In ultrasonic tissue imaging with the SA method the equivalent of the radar antenna movement is realized using the multielement probe. The probe transducers are switched in groups to create sub-apertures. Subsequent activation of the sub-apertures corresponds to the antenna movement.

One of the most important features of the SA method is that it gives a coherent imaging. In this technique we focuse on every point of reconstructed image by proper correction of RF data phases. That makes this method attractive for medical data visualization due to good resolution in the full depth of scanned area. In classical beamforming method we obtain a good resolution only in the neighborhood of the focus of the ultrasound beam. To assume high resolution in the whole imaged area multiple transmissions with different focuses are needed. However, a high number of transmissions required in this approach can significantly reduce the framerate. The SA technique potentially requires less transmissions to obtain the resolution comparable with classical beamforming method with multiple focuses.

Some basic schemes of SA in ultrasonic imaging are discussed in the publications [6, 7]. After the analysis of possibilities of the hardware implementation, it was decided to make more detailed research on the Synthetic Transmit Aperture (STA) method. The measurements using the experimental set-up were performed in order to collect the data for further studies. The basic scheme describing the STA method is presented in Fig.1.

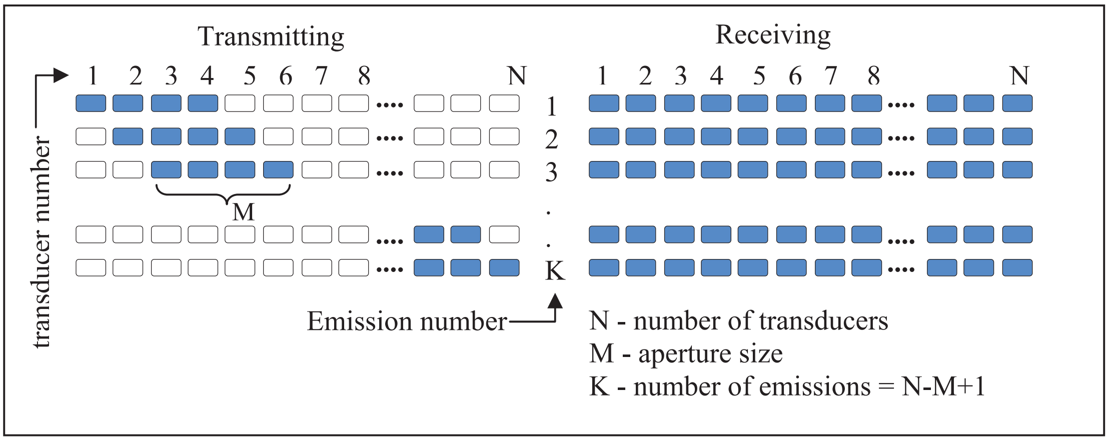

Fig.1. Scheme of STA mode

In each step the echoes are transmitted with a group of transducers (sub-aperture) of linear array. In this method the full receive aperture is used for all steps, what positively influences reconstructed images because the larger receiving aperture provides higher Signal-to-Noise Ratio (SNR) and better lateral resolution. In each step the next sub-aperture is activated until the RF data from all channels is collected.

2. MEASUREMENTS

2.1. DATA ACQUISITION

The experimental set-up, used for the RF signal acquisition, is shown in Fig.2. It consists of the specialized research ultrasonograph module, the PC with controlling software and the special wire phantom. The ultrasonograph module, called UlaOp, developed by the group of prof. P. Tortoli, is described in details in the paper [8]. This device is used in research due to its ability for performing the custom schemes of transmission and reception.

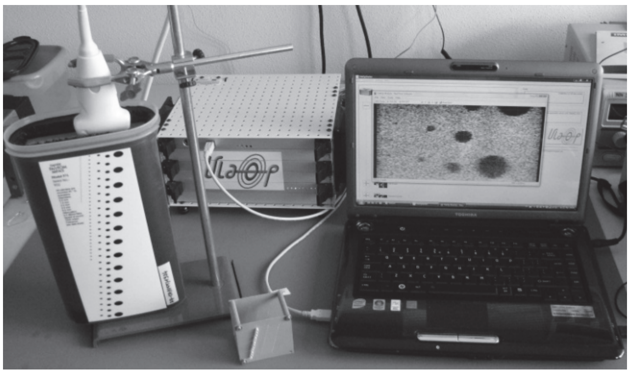

Fig.2. Experimental set-up for RF data acquisition

The wire phantom consists of many wires (Φ = 0.1 mm). The distance between wires in the phantom is 2 mm. During measurements the whole phantom is placed in the tank filled with distilled water. It is placed on rubber mate to minimize the acoustic reflections from the tank bottom.

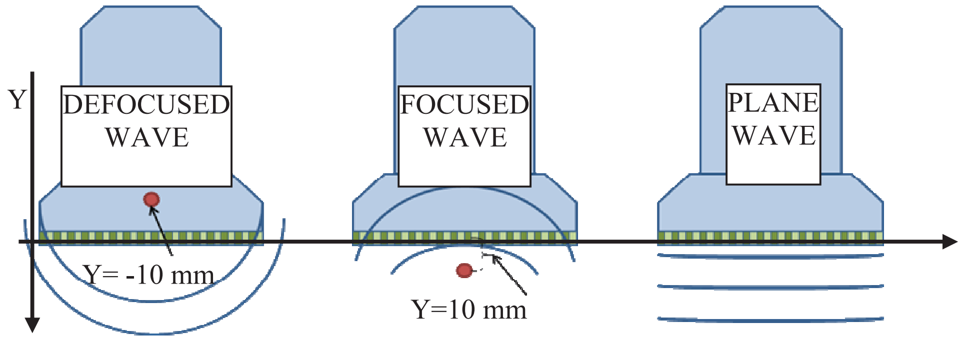

Fig.3. Wave types used in STA testing procedure

Three different transmission schemes were tested (Fig.3). The first scheme produced the defocused beam that simulated an emission from a single transducer located at depth of -10 mm. The second scheme simulated an emission from a single transducer located at depth of 10 mm. The third one produced a plane wave.

The basic set-up features:

- The probe: Esaote LA523 (pitch = 0.245 mm, BW=5.4 MHz, f_0 = 7.5 MHz)
- Transmitting aperture sizes: 4,8,16,32 (plane and focused wave) and 3,7,15,31 (defocused wave)
- Receiving aperture size: 64 elements (constant)
- Excitation pulse: f = 9.375 MHz, 3 periods of sine wave.

2.2. SIGNAL PROCESSING

In the classical way of the SA image reconstruction low quality images are fully reconstructed after every emission and then all the images are summed to create a the final high quality image [2].

In our approach the low quality images were reconstructed only in part which is in front of the active transmitting transducers. This comes from the fact that the wave-front shape is properly generated in mentioned area only, while on the edges it doesn't fulfill the reconstruction algorithm requirements. An example for plane wave emission is shown in Fig.4 where wave-front is plane in front of the transmitting aperture while it becomes circle-shaped at sides.

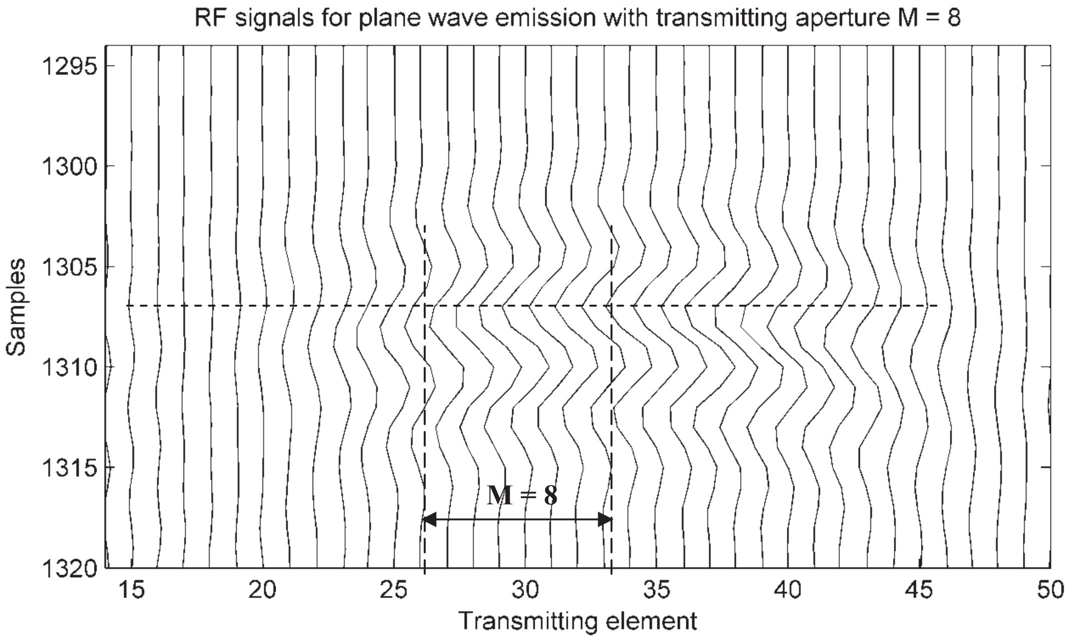

Fig.4. The wave-front shape in plane emission after reflecting from a flat reflector. Size of transmitting aperture is M=8. 10 samples are equivalent to 0.2 μs

Another advantage of narrower range of reconstruction is related to the hardware: lower amount of memory is required and the speed of computation raises.

2.3. IMAGE RECONSTRUCTION PARAMETERS

The selected basic parameters, SNR and FWHM (Full Width Half Maximum), were compared. They provide the base for the quantitative analysis of examined transmission schemes.

For every reconstructed image 3 cross-sections were made. In the A section the reference pattern which is treated as a noise in the wire phantom, was defined. The B section is an axial-cross section through the single wire where the maximal value of the signal is measured. The C section is a lateral cross-section through the wire. On the basis of A and B sections the SNRs were calculated. The B and C sections were used to determine the value of the FWHM parameter. These parameters were the bases for comparison of the STA schemes and for the selection of the wave type for further testing.

Then the chosen wave-front shape was tested in order to determine the influence of the size of the transmitting aperture on the image quality using the wire phantom. The images reconstructed with the SA algorithm were analyzed, and tested for the SNR value and the visual quality.

3. RESULTS

3.1. THE RAW RF DATA BEFORE RECONSTRUCTION

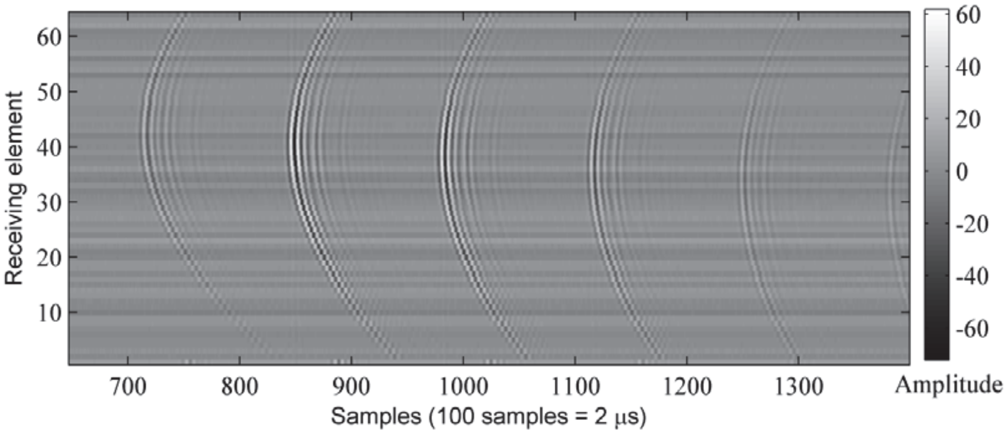

Fig.5. The raw RF data for single plane wave emission

In the Fig.4. the raw RF data is presented for the wire phantom. The reflections from the wires are visible. The next step in the processing chain is reconstruction.

3.2. COMPARISON OF DIFFERENT WAVE TYPES IN STA MODE

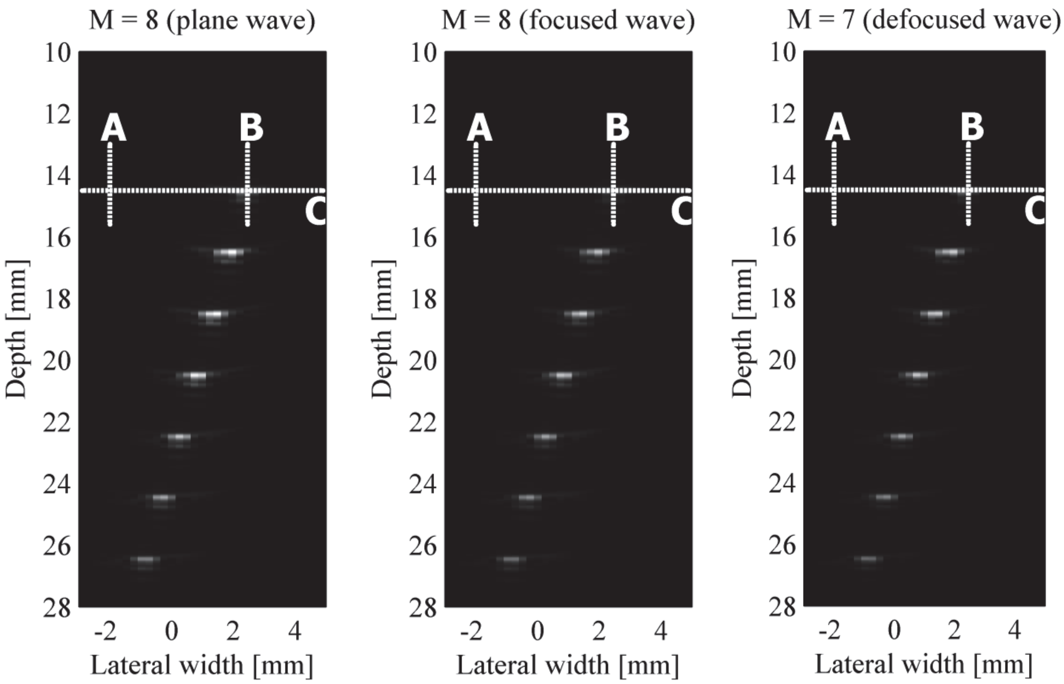

Fig.6. Reconstructed images for a) plane, b) focused and c) defocused waves

The comparison of influence of different wave types on the SNR and FWHM parameters was conducted for the constant transmitting aperture size, M = 8. The images in the same dynamic range, size and scale are shown in Fig.5.

On the reconstructed images the typical blur for point objects (point spread function) is noticeable. The noise values (section A) for all wave types vary from 14.8 to 15.8 dB.

As the signal levels are concerned (B sections) the values of the signals vary from 68.7 to 73.1 dB.

Tab.1. Comparison of SNR parameter for different wave-front types

Wave type	Noise (A) [dB]	Signal (B) [dB]	SNR [dB]	FWHM (B) [mm]	FWHM (C) [mm]
Plane	15.8	73.1	57.3	0.19	0.89
Focused	15.0	68.7	53.7	0.20	0.93
Defocused	14.8	70.9	56.1	0.20	0.90

The signal SNR values presented in Table.1. indicate that the emission with plane wave gives similar results to the emission with defocused wave. Both provide better SNR value than for the focused emission. However, plane wave is easier in practical realization. Therefore different sizes of transmitting aperture for plane wave emission were tested.

3.3. COMPARISON OF DIFFERENT TRANSMITTING APERTURE SIZES IN PLANE WAVE EMISSION

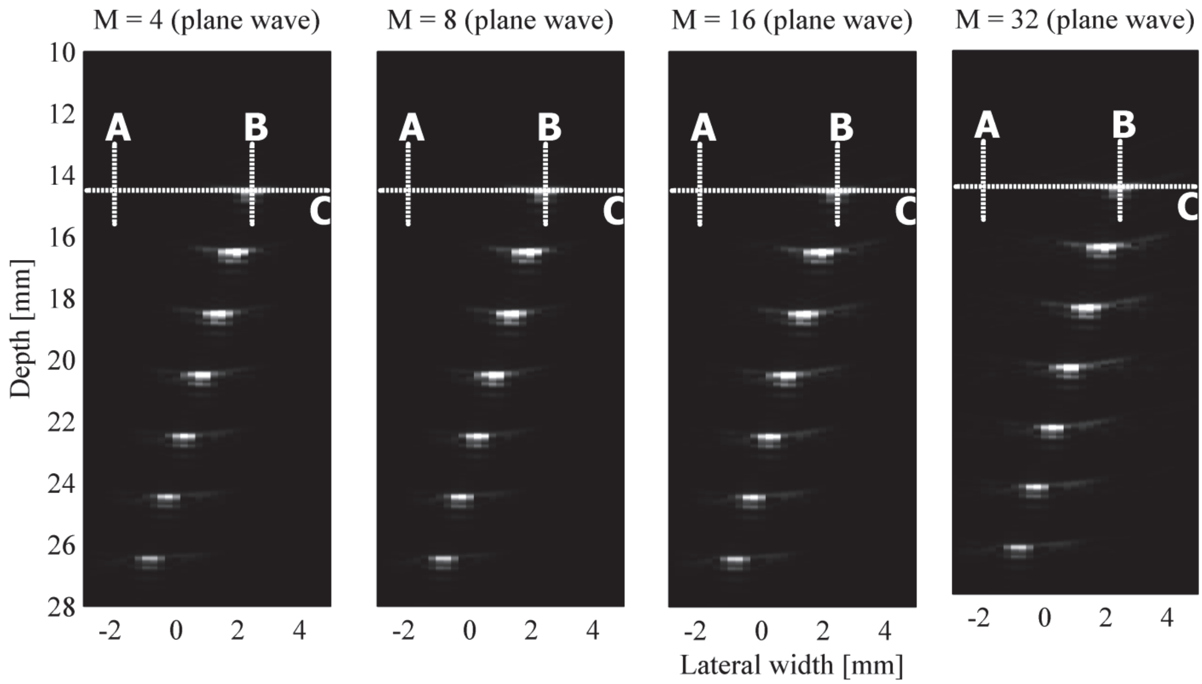

Fig.7. Reconstructed images for plane wave with transmitting aperture in the range from 4 to 32 active elements. Dynamic range is 40 dB for each image

The analysis of the results obtained in the experiment shows two phenomena which occur while using the SA technique. The first effect is related to the size of the transmitting aperture which influences the strength of the emitted signal: the broader transmitting aperture is used, higher signal level and deeper scanning range is obtained. This explains the low value of the SNR for the smallest of the tested transmitting apertures for M=4 (Fig.6. and Table.2.).

Tab.2. Comparison of the SNR parameter for different transmitting aperture sizes

Transmitting aperture size	Signal (section B) [dB]	Noise (section A) [dB]	SNR [dB]
4	63.7	13.6	50.1
8	73.1	15.8	57.3
16	80.6	21.7	58.9
32	87.6	38.4	49.2

However, broadening of the aperture size beyond some value is not justified what is confirmed by the experimental results contained in Table.2. The SNR value for the transmitting aperture size M=32 is 49.2 dB, that is almost the same value as for the aperture size M= 4 (50.1 dB) while the transmitting power is 8 times bigger. Enlarging the transmitting aperture also increases the effect of the side lobes in the final image what is noticeable in Fig.6. Hence, the size of transmitting aperture must be a compromise between the signal strength (responsible for the scanning depth and SNR) and the resolution.

To prove the merits of usage of the reconstruction region for the plane wave in front of active transmitting aperture only the additional test was performed. The SNR parameter was measured for transmitting aperture M = 8 and for different widths of reconstructed regions. The region of reconstruction is a rectangular area placed in front of the transmitting aperture. The results are presented in Fig.8.

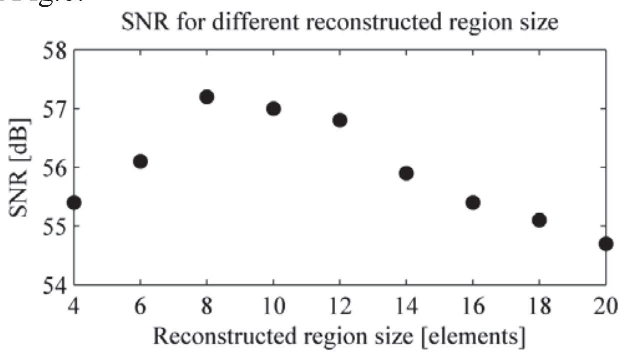

Fig.8. SNR for different reconstruction regions at constant transmitting aperture M = 8 elements

The results indicate that the width of the optimal reconstruction region is equal to the length of the active transmitting aperture. In this case the best SNR value is obtained. For the reconstruction region broader than the transmitting aperture, the SNR has lower value while the hardware requirements are higher. More memory must be applied to save the complete STA sequence. The narrower region of the image reconstruction increases the speed of computations and reduces the memory usage. However, too narrow reconstruction region results in decrease of the SNR.

4. CONCLUSIONS

The most important in the SA technique is the speed supremacy over classical beamforming. Modern ultrasonographs offer several focuses (~5 focuses) on different imaging depths in classical beamforming mode. In typical USG probe the number of transducers varies from 128 to 192 elements. Assuming the reconstruction for each line of receiving aperture in case of 5 focuses there is the necessity of 640 up to 960 acquisitions. In the considered SA technique the maximal number of acquisition is equal to the number of transducers in the probe, and might be reduced by sparsing of the transmitting and the receiving apertures [9]. These features combined with relatively good resolution make the SA an efficient algorithm. The SA algorithm is computationally complex but nowadays a modern hardware provides a sufficient performance.

The STA method was chosen for the studies. The set of different transmitting apertures in plane wave emission was tested. The best results were obtained for the transmitting apertures between 8 and 16 elements at constant receiving aperture of size 64 elements. For these aperture sizes the SNR parameters had the highest values.

The total number of emissions for the presented schemes is equal to the receiving aperture size. It is the advantage in all applications that require high framerate parameter such as cardiological imaging or tissue movement tracking.

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