ARCHIVES OF ACOUSTICS
35, 4, 635–642 (2010)

DOI: 10.2478/v10168-010-0047-8

Data Reduction Method for Synthetic Transmit Aperture Algorithm

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(*received October 13, 2010; accepted November 25, 2010*)

Ultrasonic methods of human body internal structures imaging are being continuously enhanced. New algorithms are created to improve certain output parameters. A synthetic aperture method (SA) is an example which allows to display images at higher frame-rate than in case of conventional beam-forming method.

Higher computational complexity is a limitation of SA method and it can prevent from obtaining a desired reconstruction time. This problem can be solved by neglecting a part of data. Obviously it implies a decrease of imaging quality, however a proper data reduction technique would minimize the image degradation.

A proposed way of data reduction can be used with synthetic transmit aperture method (STA) and it bases on an assumption that a signal obtained from any pair of transducers is the same, no matter which transducer transmits and which receives. According to this postulate, nearly a half of the data can be ignored without image quality decrease.

The presented results of simulations and measurements with use of wire and tissue phantom prove that the proposed data reduction technique reduces the amount of data to be processed by half, while maintaining resolution and allowing only a small decrease of SNR and contrast of resulting images.

Keywords: ultrasonic imaging, synthetic transmit aperture, data reduction, effective aperture, reciprocity.

1. Introduction

Synthetic aperture method (SA) was first developed for radar appliances (SAR – Synthetic Aperture Radar). However, due to advantages of this method it spreads to other fields of application, i.e. medical ultrasonic imaging.

Conventional beam-forming method allows to obtain the highest imaging resolution only in close neighborhood of focal point of the ultrasonic beam. To make the resolution satisfactory over the whole range of beam penetration, additional transmissions for changed focal depth are performed. Increased number of transmit-receive cycles leads to longer time of single image reconstruction. Therefore, better resolution is obtained for a price of worse frame-rate.

Synthetic transmit aperture method (STA) involves a number of transmissions with single elements emitting a spherical wave. Focusing in transmit is performed dynamically (during the received signal processing) by using a set of properly chosen time delays. It allows to virtually focus the beam everywhere. Thus, resolution is high at every point of the image (Trots *et al.*, 2008).

Nevertheless, additional dynamic focusing in transmit increases computation load of the STA algorithm significantly. Lots of data to be processed and high computational complexity can disable real-time reconstruction.

In order to lower the load of memory and arithmetic logic units (ALUs), a part of the data can be ignored. Such data reduction obviously decreases the amount of information for further reconstruction, thus it degrades the image quality. However, if the data to be neglected are chosen wisely, the image degradation is acceptably low.

The issue of data reduction was introduced in many scientific articles. Several techniques were compared (Lockwood *et al.*, 1996; Lockwood, Foster, 1996; Nikolov, Jensen, 2000) such as employment of regular, Vernier or random sparse arrays. Optimization attempts were based on effective aperture approach (Lockwood *et al.*, 1996; Lockwood, Foster, 1996; Nikolov, Jensen, 2000; Behar, Adam, 2005). Data reduction for case of 2D probes was considered as well (Lockwood, Foster, 1996; Nikolov, Jensen, 2000).

The papers mentioned above put tension on obtaining possibly the best shape of effective aperture. This allows to minimize the negative influence of grating lobes which are induced by change of spatial sampling frequency.

Proposed scheme of data reduction is based an assumption that part of the data is duplicated. Thus, these data can be neglected without serious effects in the final image.

2. Theory

2.1. Effective aperture approach

The Effective Aperture (EA) of an array is the receive aperture that would produce an identical two-way radiation pattern, assuming that the transmit aperture is a point source (Lockwood *et al.*, 1996). The EA can be calculated as a convolution of the transmit and receive apertures. However, some data reduction techniques make the receive aperture change between consecutive transmissions (e.g. Fig. 1b). In such cases, a simple convolution is useless but one can

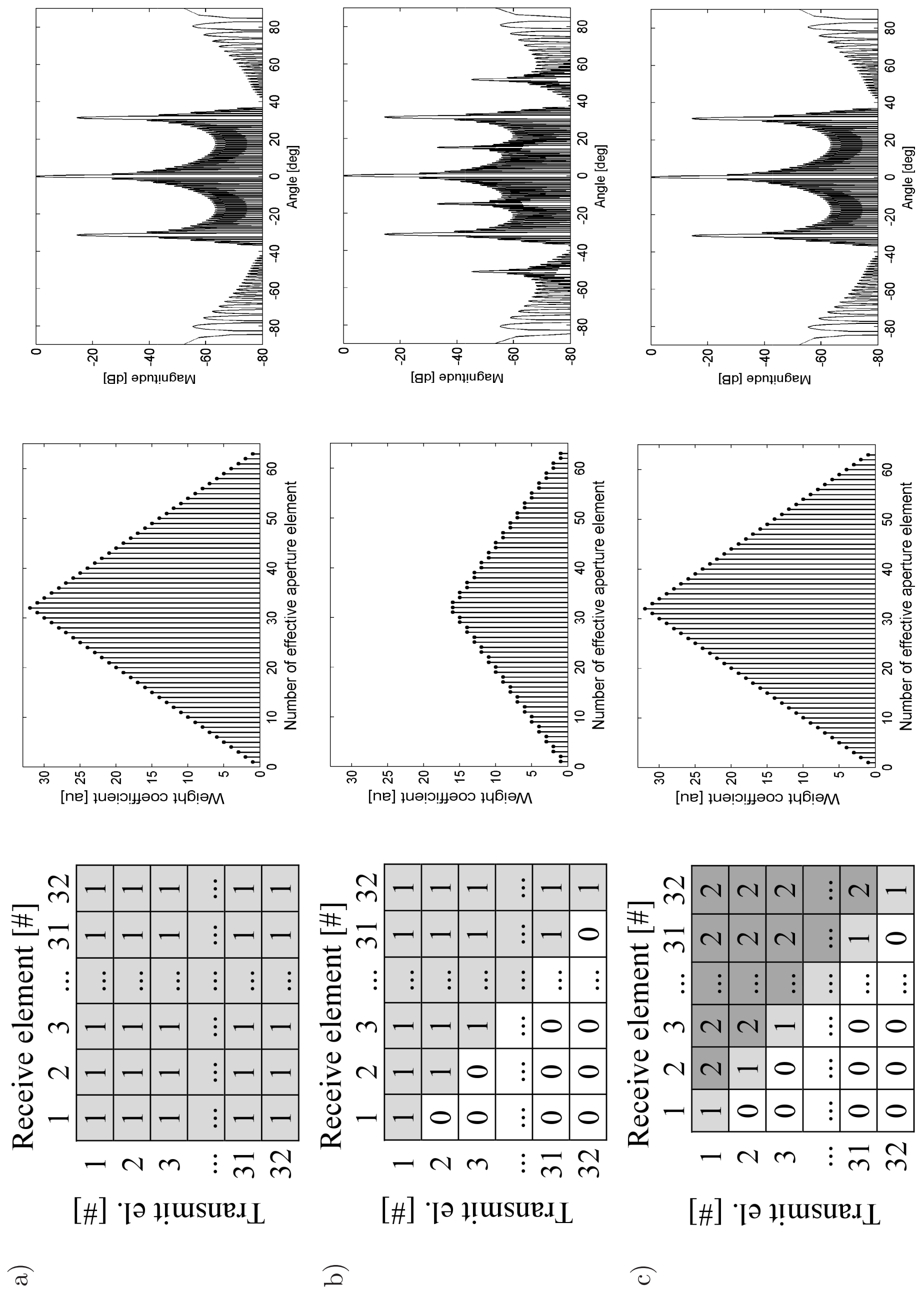

Fig. 1. Transmit-receive schemes (left), effective apertures (middle) and shapes of effective transmit-receive beam (right) for STA algorithm: a) full STA, b) reduced STA, c) reduced STA with effective aperture compensation. 32-elements linear probe with pitch 0.48 mm and element width 0.4 mm. Mean transmit frequency 6 MHz, speed of sound 1500 m/s

employ a more general way of EA calculation with use of a transmit-receive scheme. It involves summation of the elements along consecutive diagonals of the scheme (Fig. 1). Having the EA calculated it is possible to obtain a more desired function which is a two-way radiation pattern.

The effective radiation pattern is a Fourier transform of the EA and is a function of spatial frequency. However, it can be easily converted into a function of an angle as the spatial frequency is given as $\sin\theta/\lambda$ where θ and λ, denotes angle and wavelength respectively.

The two-way radiation pattern allows to predict the imaging quality in the far field. One can specify the lateral resolution, direction and level of grating lobes etc. Therefore the concept of EA allows to easily design a transmit-receive scheme which will provide a desired imaging quality.

2.2. Reciprocity approach

The reciprocity, in context of the STA method, means that a signal obtained with use of any pair of probe elements is the same, no matter which element transmitted and which received. This can be described by an equation:

$$p_{m,n}(t) = p_{n,m}(t), \tag{1}$$

where $p_{m,n}(t)$ is the signal received with transducer n, while transducer m was transmitting and $p_{n,m}(t)$ is the corresponding signal in case of exchanged roles of the transducers. Obviously, such a formulation is far from reality as there are many phenomena which give a contribution to the signals, making them different one from another within each pair of elements. However, these contributions can be neglected in order to create a simple model of the signal. The omitted phenomena are in particular: differences between transmit and receive transducer characteristics, nonlinear effects, noise and multiple scattering (Born approximation - wave can be scattered in examined object once only).

In accordance with proposed signal model and Eq. (1), half of the data is a duplicate of another half. Therefore, negligence of these signal copies will not decrease the possessed information. Thus, the reciprocity concept allows to reduce the data with no risk of information loss.

3. Proposed method

Introduced data reduction method bases on both the reciprocity and effective aperture approaches. According to the reciprocity concept we neglect part of the data which is duplicated. Then, using the effective aperture method, negative changes in two-way radiation pattern are compensated.

Figure 1a shows classical STA scheme – probe elements transmit one by one and after each transmission, the ultrasonic echoes are being received with all elements. The effective aperture for this scheme has a triangular shape. For pitch between probe transducers equal to 0.48 mm, transmit frequency 6 MHz and speed of sound 1500 m/s, grating lobes appear at ±31.5°. Omission of part of the signal (Fig. 1b) which is below the main diagonal of the scheme, generates a stair-like shape of effective aperture and thus, additional grating lobes at ±15° and ±51.5° occur. This negative effect can be easily eliminated by doubling the weighting factors above the main diagonal of the scheme (Fig. 1c). As a result, the effective aperture and effective transmit-receive beam return to their previous shape.

It must be stated that the scheme in Fig. 1c has an ideological value only. Its practical application brings non-uniform improvement in conditions of data transmission, memory requirements and ALUs load. According to the scheme in Fig. 1c, for the first transmission the system requirements are unchanged and decrease with the number of transmission. It is most preferred to load the hardware uniformly. This can be achieved by replacing some signals $p_{m,n}$ by $p_{n,m}$ in such a way that a number of nonzero elements is identical for every row of the transmit-receive scheme.

Table 1. Example of sparse transmit-receive scheme which provides uniform load of system resources.

Transmit element [#] \ Receive element [#]	1	2	3	4	…	30	31	32
1	1	0	2	0	…	0	2	0
2	2	1	0	2	…	2	0	2
3	0	2	1	0	…	0	2	0
4	2	0	2	1	…	2	0	2
…	…	…	…	…	…	…	…	…
30	2	0	2	0	…	1	0	2
31	0	2	0	2	…	2	1	0
32	2	0	2	0	…	0	2	1

4. Measurements

Analysis of presented data reduction technique involved simulations and laboratory experiments. Numerical model included 32-element linear array with pitch of 0.48 mm, emitting pulses at mean frequency equal to 6 MHz. Examined object was a point scatterer immersed in water, 20 cm away from the probe. According to STA scheme, a simulated acquisition was performed. Images were reconstructed with use of a pure simulated signal and a signal with noise added.

Further analysis was based on lab experiments. A set of beam-former SG3 (produced by ECHOSON), linear array LA510 (pitch = 0.48 mm) and programmable acquisition unit (designed and constructed in the Department of Ultrasound of the Institute of Fundamental Technological Research of the Polish Academy of Sciences) was used to obtain the STA echo signal. As in the case of simulation, only 32 elements of the probe were used and pulse's mean frequency was equal to 6 MHz.

As an examined object, a wire phantom and a tissue phantom were used. The wire phantom included a steel wire ($\varphi = 0.2$ mm) immersed in distilled water. The tissue phantom (model 571, produced by Dansk Fantom Service) contained cysts of low echogenicity.

5. Results

Reconstruction with use of noise-free simulated data generated identical images, no matter if the data were reduced (Fig. 1c or Table 1) or not (Fig. 1a). The experiment confirmed that the presented data reduction method is based on true rationale.

Addition of noise to the simulated data resulted in Signal to Noise Ratio (SNR) differences. While the data were reduced by half, the SNR decreased by 3 dB which is in agreement with the theory of signal processing. As shown in Fig. 2, both: axial and lateral resolution are unaffected by proposed data reduction technique.

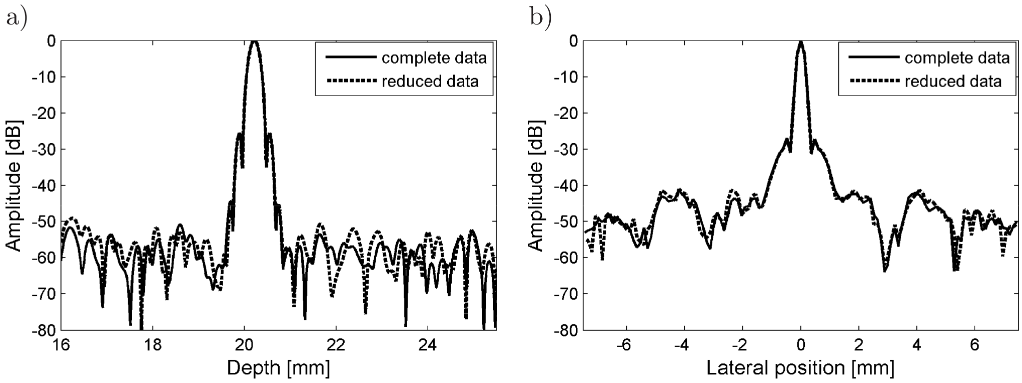

Fig. 2. a) Axial and b) lateral cross-sections of the point scatterer image obtained with use of complete and reduced data.

Further results refer to experimental data. Reconstruction of the data obtained with use of wire phantom leads to conclusions similar to those in simulation case. In consequence of data reduction, the SNR of the reconstructed image decreases approximately by 3 dB. As shown in Fig. 3a, axial resolution is unaffected by the proposed method. A lateral cross-section through the wire exhibits negative changes – sides of Point Spread Function (PSF) are significantly increased, which is visible in Fig. 3b. However, this phenomenon occurs at level of −40 dB which is low enough to be accepted. Nevertheless, the change of PSF due to data reduction needs to be explained.

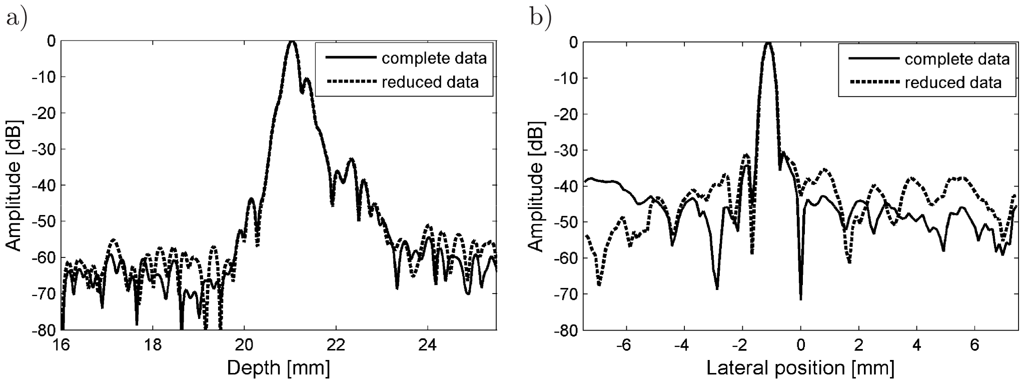

Fig. 3. a) Axial and b) lateral cross-sections of the wire image obtained with use of STA algorithm from complete and reduced data.

Examination with use of signal from tissue phantom allowed to estimate a contrast decrease due to data reduction. The contrast was calculated as a difference between mean amplitude outside and inside the cyst. In case of complete data (Fig. 4a), the contrast value was 12.5 dB while after data reduction (Fig. 4b) it decreased to the level of 11.1 dB.

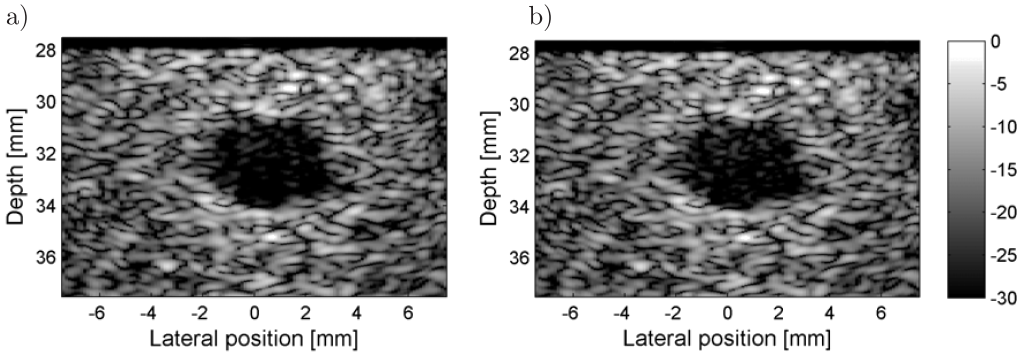

Fig. 4. Images of tissue phantom reconstructed with use of STA algorithm from a) complete data and b) reduced data. Dynamic range is 30 dB.

6. Conclusions

The presented data reduction method for STA algorithm allows to decrease the amount of the data (and consequently, the hardware resources) nearly by half while maintaining good quality of imaging. Results of simulations and lab experiments with use of wire phantom proved that imaging resolution is unaffected by the data reduction procedure while the Signal to Noise Ratio decreases by 3 dB. The decrease of contrast value (which was calculated for images of the tissue phantom) due to data reduction is about 1.4 dB. In case of low contrast images, such degradation can prevent from distinction of important tissue structures. However, for conventional dynamic range of images (a few tens of dB) this decrease appears to be acceptable. Nevertheless, this research includes no consideration on contrast parameters of particular biological structures.

Presented results confirm that the introduced algorithm is an efficient way of data reduction for the STA technique. Proposed method allows to lower the hardware requirements of the STA system nearly by one half, while introducing only a small decrease of the imaging quality.

Acknowledgments

Project POIG.01.03.01-14-012/08-00 co-financed by the European Regional Development Fund under the Innovative Economy Operational Programme. Project is governed by Ministry of Science and Higher Education, Poland.

Preliminary results of this study were presented at the Open Seminar on Acoustics, Gliwice, September 20–24, 2010.

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