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LABORATORY SETUP FOR SYNTHETIC APERTURE ULTRASOUND IMAGING

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The paper describes the synthetic transmit aperture (STA) imaging system with a single element transmitting and multi-element reception in medical ultrasound. Synthetic aperture method allows to achieve high electronic signal-to-noise ratio and good contrast resolution. A laboratory setup for acquisition of RF signals from linear transducer array was built. Simulated multichannel acquisition by multiplexing individual transducer was performed. In experiments 32-element linear transducer array with 0.48 mm inter-element spacing and a burst pulse with time duration 100 ns was used. Single element in the transducer transmitting aperture was used to generate a spherical wave covering the full image region. The echo signals were sampled independently by individual elements for each transmission. The comparison of 2D ultrasound images of wire phantom obtained using STA method and standard linear array scanning with commercial ultrasonograph is given. The results show excellent image resolution of the STA method and its robustness to refraction, attenuation and multiple reflection of ultrasound waves.

Keywords: ultrasound imaging, synthetic aperture, contrast resolution.

1. Introduction

Medical ultrasound imaging is a technique that has become prevalent medical imaging techniques since it is easily accessible, less expensive, safe, simple to use and produces images in the real time. However, images produced by an ultrasound imaging system, must be of sufficient quality to provide accurate clinical interpretation. The most commonly used image quality measures are spatial resolution and image contrast which can be determined in terms of beam characteristics of an imaging system: beam width and side-lobe level. In the design of an imaging system, the optimal set of system parameters is usually found as a trade-off between the side-lobe level and the beam width of an imaging system.

In conventional ultrasound imaging system, when only one transducer is used, the quality of images directly depends on the transducer acoustic field. Also in conventional ultrasound imaging the data are acquired sequentially one image line at a time that puts a strict limit on the frame rate that is important in real-time imaging system. Low frame rate means that moving structures (e.g. heart valves) are not perfectly reproduced and diagnosis may be impaired. This limitation can be lifted by employing synthetic aperture (SA) imaging. Here data are acquired simultaneously from all directions over a number of emissions, and the full image can be reconstructed from this data. The SA method aspects are discussed in [2, 8].

In SA method as well as in conventional method the peak acoustic power limits the signal-to-noise ratio (SNR) in ultrasound images. This limitation can be overcome by using long wide band coded transmitting sequences and compression techniques on the receiver side [1]. Longer signals allow to obtain the results similar to that obtained using single short pulses but with much higher amplitude [3, 9]. There are several papers in literature concerning similar boundary-condition problem of signal compression in medical diagnostic imaging [4–7]. In comparison with other coded excitation schemes, such as chirp, pseudo-random sequences and Barker codes, the CGS allowed virtually side-lobe free operation.

In this paper a STA method for medical ultrasound imaging system was implemented and tested by using radio frequency (RF) data from wire phantom. The results obtained using STA method were compared with the results obtained using conventional composite transmit focusing method. The investigated STA method increased the frame rate and allowed to obtain the significantly better image quality.

2. Synthetic aperture ultrasound imaging

One of the important processes in ultrasound imaging systems is beamforming. There are many different beamforming methods. In this paper the STA method is discussed only. In STA imaging, at each time one array element transmits a pulse and all elements receive the echo signals. The advantage of this approach is that a full dynamic focusing can be applied to the transmission and the receiving, giving the highest quality of an image.

The method for acquiring synthetic aperture ultrasound images is shown in Fig. 1. A single element in the transducer aperture is used for transmitting a spherical wave covering the full image region. The received signals for all or part of the elements in the aperture are sampled for each transmission. Using the STA, dynamic focusing can be performed on the synthetic transmit aperture and the receive aperture, as well.

In STA method focusing is performed by finding the geometric distance from the transmitting element to the imaging point and back to the receiving element. The structure of the synthetic aperture and geometric relation between the transmit and receive element combination is shown in Fig. 2.

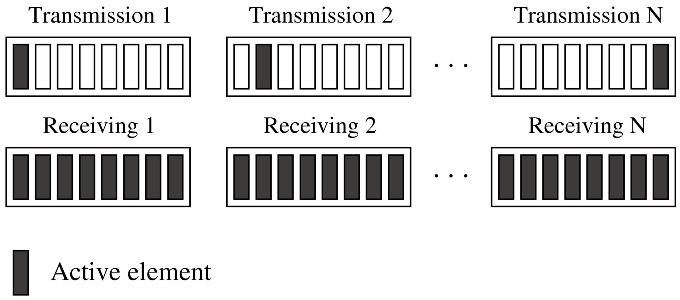

Fig. 1. Principle of STA imaging method.

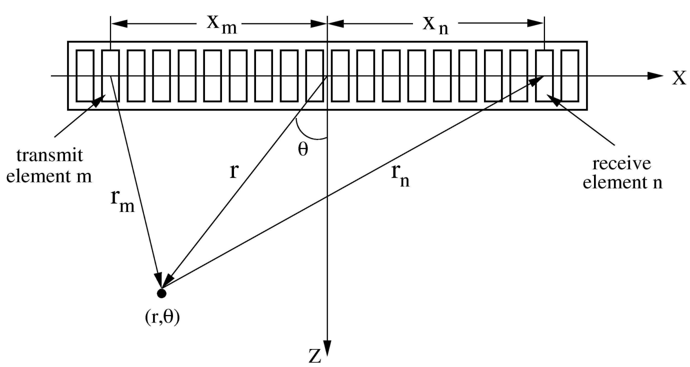

Fig. 2. Geometric relation between the transmit and receive element combination and the focal point.

When a short pulse is transmitted by element m and the echo signal is received by element n, as shown in Fig. 2, a round-trip delay is

$$\tau_{m,n} = \tau_m + \tau_n, \tag{1}$$

where (m, n) is a transmit and receive element combination, $0 \leq m, n \leq N - 1$.

According to Law of Cosine, the distances from the point to the m-th element, r_m, and to the n-th element, r_n, are

$$r_m = \sqrt{x_m^2 + r^2 - 2x_m r \sin\theta}, \qquad r_n = \sqrt{x_n^2 + r^2 - 2x_n r \sin\theta}, \tag{2}$$

where x_m, x_n are the positions of the m-th and n-th elements, respectively and r is distance between synthetic aperture centre and the point (r, θ).

The delays for m-th element and n-th element are

$$\tau_m = \frac{1}{c}\left(r - r_m\right), \qquad \tau_n = \frac{1}{c}\left(r - r_n\right). \tag{3}$$

For an N-element array for each point in an image, the A-scan signal can be expressed as

$$a\left(r, \theta\right) = \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} y_{m,n}\left(\frac{2r}{c} - \tau_{m,n}\right), \tag{4}$$

where $y_{m,n}(t)$ is the echo signal and $\tau_{m,n}$ is beamforming delay for the (m, n) receive and transmit element combination given in (1). The first and second summations correspond to transmit and receive beamforming.

3. Ultrasound imaging system

A simplified ultrasound imaging system is shown in Fig. 3.

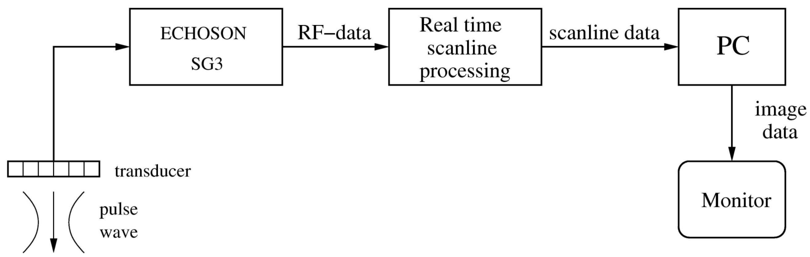

Fig. 3. Block diagram of the ultrasound imaging system.

Transducer transmits pulsed ultrasound waves, and receives reflected echo signals. Echoson SG3 (Echoson, Puławy, Poland) analog beamformer enables full control of selected 32 consecutive channels/transducers of a linear array transducer. Parameters of transmission and reception are programmable from a PC using a serial port (RS-232). Using the beamformer one can switch on arbitrary transmit and receive channels in the selected 32 channels aperture. The second block, real time scanline processing, is responsible for steering of the ultrasound waves. This block extracts the RF data, acquires it and send to the PC. Next, the collected digital data were processed offline and displayed on the monitor. All post processing and display is done on the computer using Matlab® routines. The processing creates 2D ultrasound imaging focused in every point of image.

The system enabled us to perform simulated multichannel acquisition for synthetic aperture imaging. Using a single channel digitizer and switching receiving transducers we were able to collect RF data for up to 32 lines. The data acquisition in synthetic aperture imaging is radically different from a normal ultrasound system since data have to be stored for all receiving transducers and for a number of emissions. Repeating this procedure for each of the 32 transducers we obtain 1024 RF lines that are the input to the synthetic aperture algorithm, Eq. (4).

4. Experimental results and discussion

The 32-element linear transducer array with 0.48 mm inter-element spacing and a burst pulse with time duration 100 ns (a half-cycle at nominal frequency 5 MHz) were used. The inter-element space is about 3λ. All elements are used for both transmitting and receiving. One single element in the transducer transmitting aperture was used to generate a spherical wave covering the full image region. Each time only one element transmits the probing signal and all elements receive the echoes. The transmit and receive elements combination gives a total of 32×32 possible RF A-lines. All these possible A-lines echo signals were sampled independently at 50 MHz and stored.

The wire phantom, used in the experiments, consisted of 24 wires 0.1 mm in diameter positioned every 2 mm axially and at an angle of 75 degrees. This phantom allows to examine the axial and lateral resolution at various depths in the ultrasound image as well as focal and dead zone registration.

Three of 1024 (32×32) received RF echo signals which were digitized and stored in the PC are shown in Fig. 4.

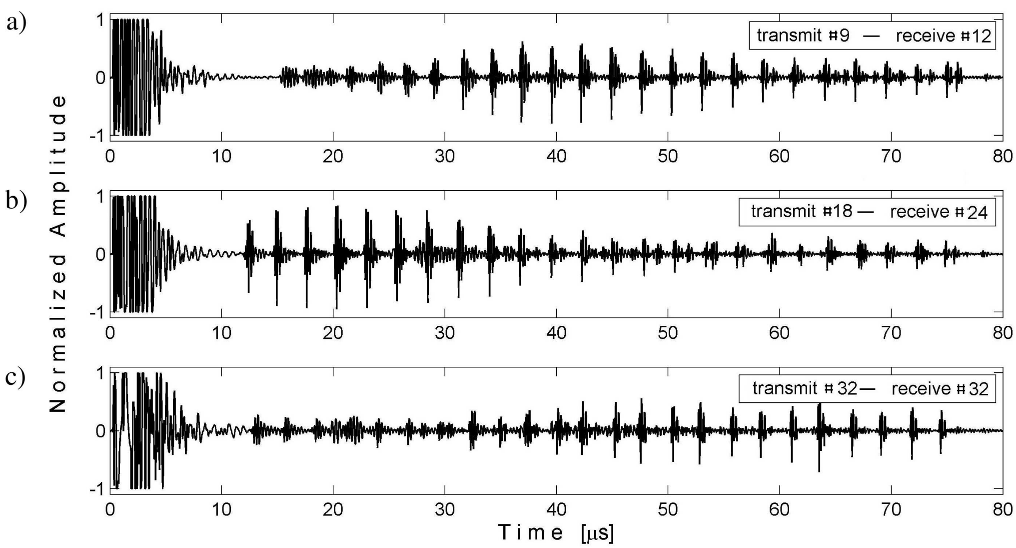

Fig. 4. The recorded by PC RF echo signals: a) element #9 is transmitting – element #12 is receiving, b) #18 transmitting – #24 receiving, c) #32 transmitting – #32 receiving.

All these RF echo signals are different and echo time position and signal amplitude in every case depends on sound field and geometrical position of transmitted and received transducers. After all emmissions the full set of the RF A-lines echo signals needed to reconstruct one 2D B-mode ultrasound image is obtained. For this aim the RF lines are input to the synthetic aperture algorithm which calculate the time delay for every imaging point.

As was mentioned above, a single element in the transducer aperture is used for transmitting a spherical wave covering the full image region. The received signals for all or part of the elements in the aperture are sampled for each transmission. This data can be used for making a low resolution images (Fig. 5a–5c), which is only focused in receive due to the unfocused transmission. Focusing is performed by finding the geometric distance from the transmitting element to the imaging point and back to the receiving element and can be obtained from Eq. (2). These low resolution images need to be added coherently to form the final high resolution image (Fig. 5d).

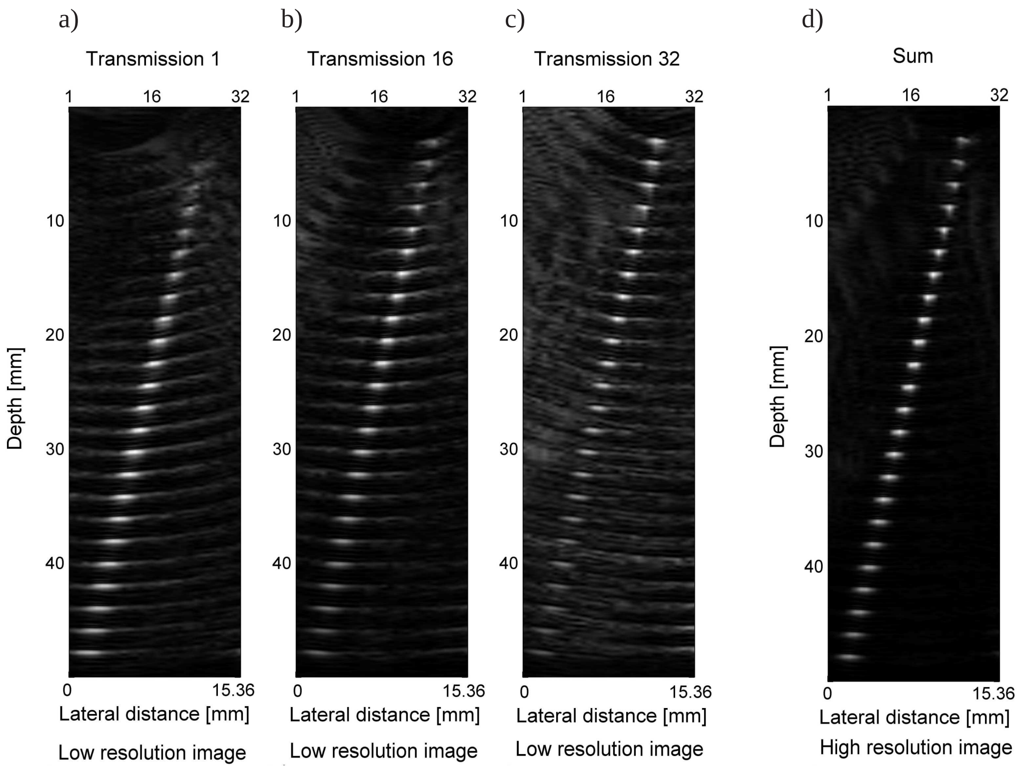

Fig. 5. Low resolution images combined to produce a high resolution image. One element transmit at the time, while all is used to receive. The images are then added into one high resolution image.

The comparison of the reconstructed wire phantom images obtained using STA method and standard linear array scanning with commercial ultrasonograph Antares (Siemens, Mountain View, CA, USA) is shown in Fig. 6. The 128-elements linear transducer array with 0.3 mm pitch (VF13-5) and a burst cycle pulse at nominal frequency 10 MHz were used in ultrasonograph.

The maximum quantity of focal points, which is equal to 8, was chosen in the ultrasonograph, they are marked by triangles in the bar. It needs to be noted, that frame rate in that case dramatically decreases down to 4 fps (in the case of one focal point it is equal to 30 fps). Such frame rate is definitely insufficient to normal examine the dynamically moved organs, such as heart, where high frame rate even up to 50 fps is requirement.

In Fig. 6 it can be easily seen, that axial and lateral resolutions at the top and at the bottom parts of the image are different and depend on the focal point quantity in these regions.

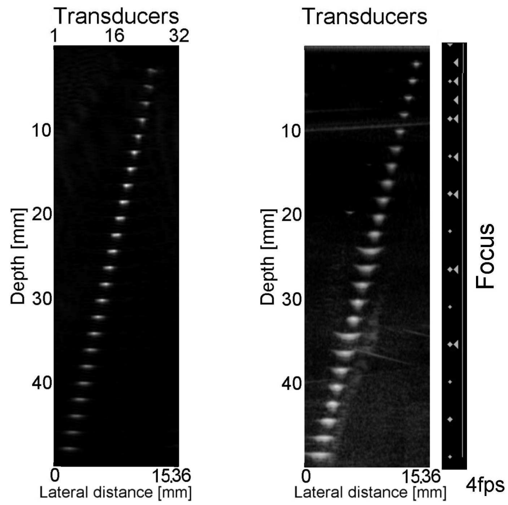

Fig. 6. 2D B-mode images of the wire phantom obtained using STA method (left) and commercial ultrasonograph Antares (right). The bar shows the focal points.

The images show the performance of the STA method. It allows to obtain better resolution than the conventional ultrasound system with an increased frame rate. The results obtained show the effectiveness of the STA method and its robustness to the refraction, attenuation, and multiple reflection of ultrasound waves.

5. Conclusion

The work concerns the development and investigation of the STA method that allows to increase system frame rate and thus to improve the image quality. The paper explains how SA ultrasound imaging can be acquired and processed. The STA method was investigated experimentally. The phantoms, which contain wires, were used to test general image quality.

The image reconstructed using the STA method gives a better image resolution than standard ultrasonograph, while frame rate is not decreasing. The disadvantage of the STA system is that storage and processing requirements are higher than in conventional beamforming, because the RF data must be stored for every combination of transmit and receive elements, and later recombined.

The synthetic aperture method can be applied in standard ultrasonography. Introduction of STA method in medical ultrasound increases effectiveness and quality of the ultrasound diagnostic.

Acknowledgments

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