Imaging Quality of the Classical Beamforming, SAFT and Plane Wave Imaging – Experimental Results

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Abstract - **The synthetic aperture focusing techniques (SAFT) are well known and widely deployed in radar techniques. Increasing processing power of modern computers allows effective implementation of various SAFT schemes in medical ultrasound systems with multi-element probes. The advance of the SAFT over the classical beamforming (BFR) is dynamic focusing in receive and transmit as well, which brings high resolution on every imaging point. We intend to develop the ultrasound imaging platform with some of the SAFT schemes implemented. The choice of the scheme must be preceded by examination of the imaging quality parameters. The results of the comparison of different SAFT schemes with conventional beamforming are presented in the paper. The results indicate that SAFT schemes can work better than BFR scheme. For example, for some point located near the center of the image the full width at half maximum (FWHM) was equal approximately 0.5, 0.4 and 0.3 mm, while the contrast-to-noise ratio (CNR) was equal 18, 19, and 19 dB for BFR, STA and PWI respectively.**

Keywords – Ultrasonic imaging, SAFT, Plane Wave Imaging

I. Introduction

A new ultrasonic platform is being built in our laboratory [1]. The developed hardware allows for very demanding signal processing, which enables to realize new imaging methods, therefore a choice of the best technique must be made. The problem of the selection of the optimal imaging strategy is discussed by Tong et. al [2]. However, the study is dedicated to different applications and imaging conditions. Our study refers to a case of a relatively shallow imaging with use of a linear array.

We started our research on optimal imaging technique from a choice of the best transmission scheme. There are three widely described approaches [3,4]:

- classical beamforming (BFR) with a beam emitted from a certain aperture, physically focused at a certain depth,
- synthetic transmit aperture (STA) with a spherical wave-front emitted form a single element or a small group of elements,
- plane wave imaging (PWI) with a tilted plane wave-front emitted from a large aperture.

Each of above schemes is described by a set of parameters which decides on quality of resulting images. In order to evaluate it, we used following factors:

- signal-to-noise ratio (SNR),
- contrast-to-noise ratio (CNR),
- full width at half maximum (FWHM),
- an arbitrary assessment of cross-sections of wire images.

At first we tried to find optimal parameters values for each transmit technique. Then we compared the optimized schemes with one another and drew conclusions

II. Methods

The classical beamforming technique (BFR) involves sequential transmitting of focused beams along certain directions. Echo signal collected at a single transmit-receive cycle is used for the reconstruction of a single image line corresponding to beam position. Due to the line-by-line image formation the BFR is strongly limited in terms of achievable frame-rates. Moreover, the application of physical focusing produces high quality images only at focal depth. This issue can be partially overcome by multiple focusing, however it results in further reduction of the frame-rate.

Constraints mentioned above do not occur in synthetic aperture (SA) imaging techniques. While the BFR applies dynamic focusing only in receive, the SA methods perform it in transmit as well. This results in high quality throughout the image. Furthermore, unlike the BFR the SA involves insonification of the entire region of interest (ROI) at a time. Therefore, a single transmission is sufficient to produce a whole image instead of a single line as in case of the BFR. The result is referred to as a low resolution image (LRI). To obtain a high resolution image (HRI), a number of subsequent LRIs is summed. Since the number of LRIs per HRI is adjustable, the SA techniques can be optimized for image quality or frame rate. Such constitution makes the SA methods flexible and thus universal.

The most widely described SA techniques are synthetic transmit aperture (STA) and plane wave imaging (PWI). The STA [3] involves sequential emissions of quasi-spherical waves from small sub-apertures which are shifted every cycle, while the PWI [4] uses quasi-planar waves emitted from whole probe aperture at a different angle in each cycle. Both techniques offer enhanced quality and open new possibilities in ultrasound imaging. Therefore, in our study we compared them both together with classical BFR.

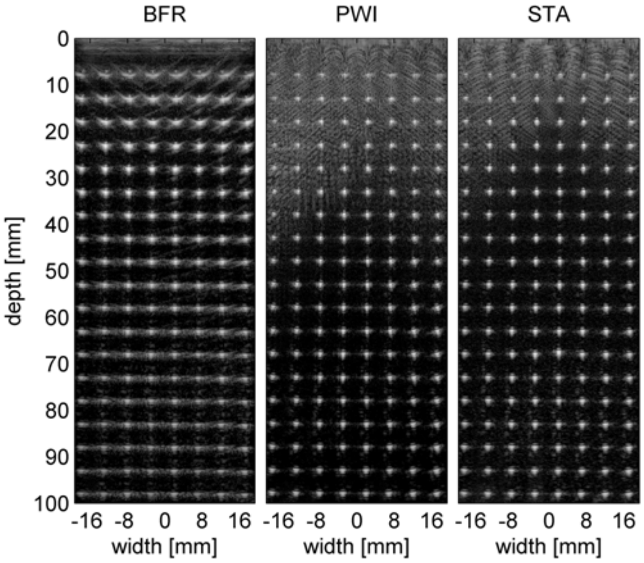

Figure 1. B-mode images of wire phantom for examined schemes.

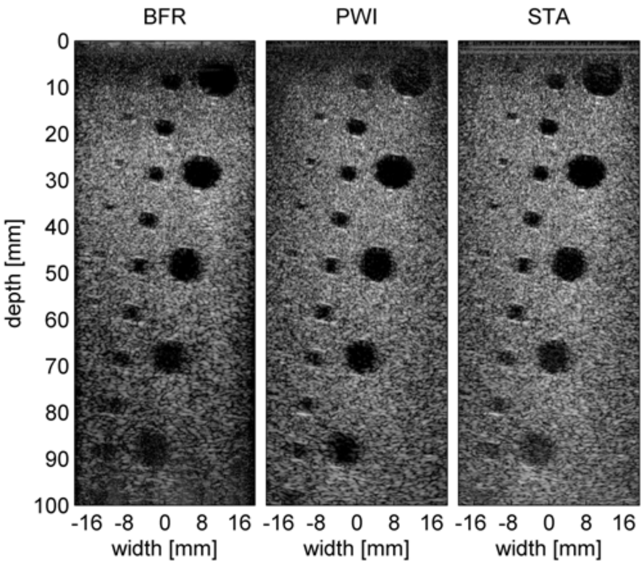

Figure 2. B-mode images of tissue phantom for examined schemes.

III. Measurements

Data were acquired from wire and tissue phantoms. The first phantom consists of wires of 0.06 mm in diameter immersed in water, forming a structure shown as a B-mode image in Fig. 1. The tissue mimicking phantom (Dansk Fantom Service, model 571) whose B-mode image is in Fig. 2, contains cylinders of various diameter and low echogenicity, which mimic biological cysts.

The raw, pre-beamformed data were collected with use of an ultrasonic scanner (SonixTOUCH, Ultrasonix, Canada) with linear probe L14-5/38. Short pulses of 4 MHz frequency were used as an excitation. Three types of transmit techniques were examined: classical beamforming (BFR), synthetic transmit aperture (STA) and plane wave imaging (PWI). Each transmit scheme was first optimized by adjustment of parameters such as aperture width, focal depth, etc. Then the best schemes of all types were compared in terms of FWHM, SNR, CNR and arbitrary assessment of B-mode images and their cross-sections.

IV. Results

As a result of the initial optimization the following values of parameters were selected for each technique:

- BFR: 32-element aperture, 30 mm focal depth,
- STA: 1- and 2-element aperture,
- PWI: angles from -30° to 30° in increments of 0.5°.

Above schemes were next compared with one another and are presented below.

Arbitrary assessment of reconstructed B-mode images indicates that both STA and PWI offer better resolving power than BFR (Fig. 1). Moreover, the tissue phantom images (Fig. 2) suggest that PWI provides better contrast at deeper regions than other methods and therefore it allows for better penetration.

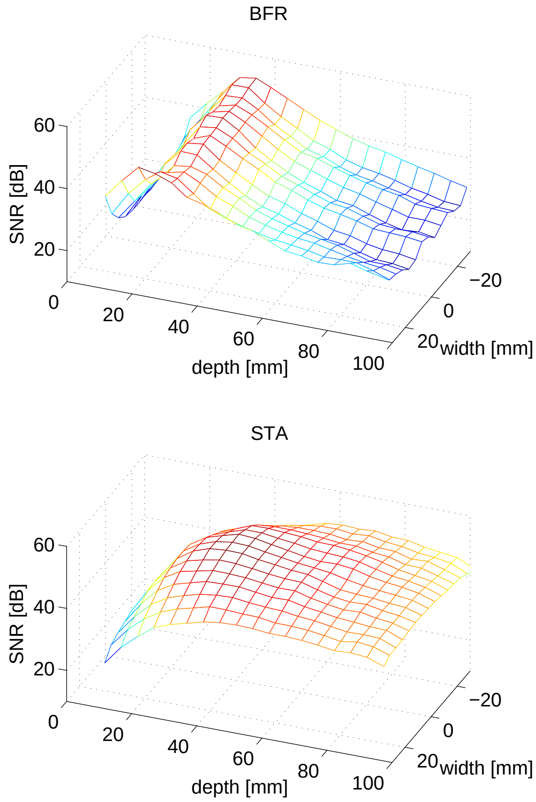

Figure 3. The SNR function for BFR and STA schemes.

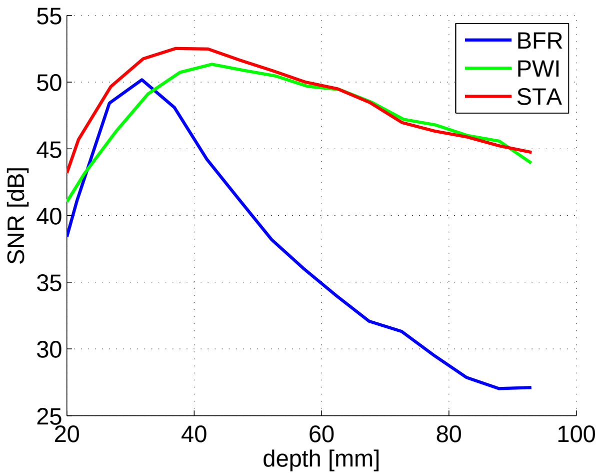

Figure 4. The SNR as a function of depth - axial cross-section of the data shown in Fig. 3.

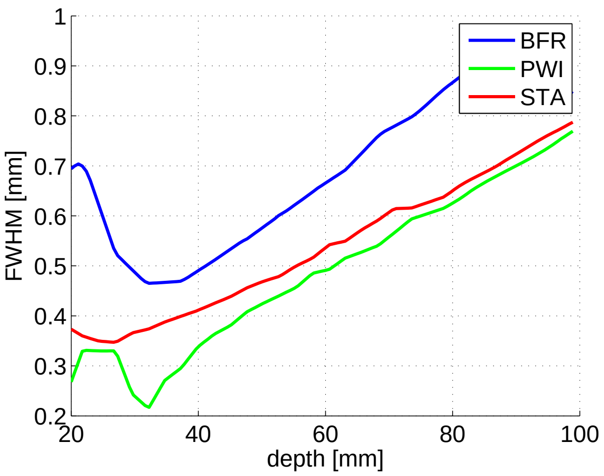

Figure 5. The FWHM as a function of depth.

Images of wire phantom (Fig. 2) were a base for analysis of FWHM and SNR. Results confirm that both synthetic aperture techniques outperform the classical beamforming. The SNR (Fig. 3a, 4) of the BFR images is at a reasonable level only at focal depth (30 mm) and decreases rapidly with distance (roughly 4 dB/cm), while for the PWI and the STA it decreases more slowly (about 1.5 dB/cm). Also the FWHM is lower (better) by 0.1-0.2 mm in case of the synthetic aperture techniques (Fig. 5).

To complete the comparison of the wire phantom images, cross-sections of the wires at 30 mm, 60 mm and 90 mm depths are presented (Fig. 6). Again the BFR fails with its wide main-lobe and high-level of side-lobes (-15 dB). The PWI seems to offer the narrowest main-lobe at small depth, however in deeper area it produces higher level of side-lobes (-25 dB) than the STA (-30 dB).

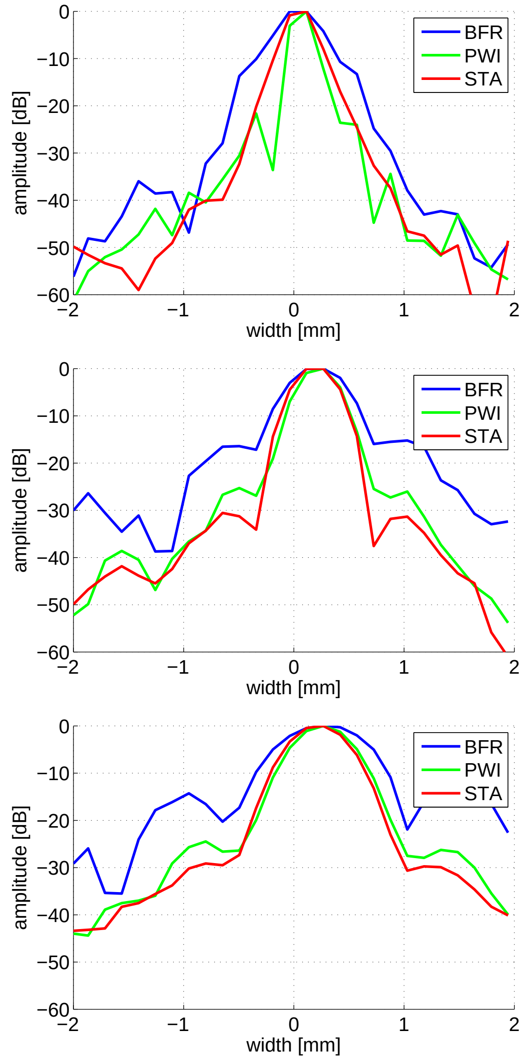

Figure 6. Cross-sections through wires at depth a) 30 mm, b) 60 mm and c) 90 mm.

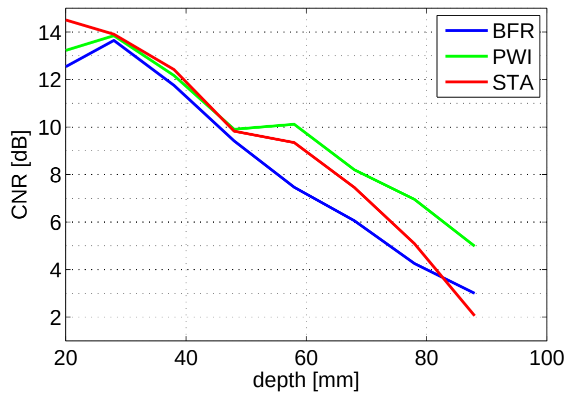

Figure 7. The CNR as a function of depth.

Another image quality parameter - CNR - is derived from the tissue phantom images (Fig. 2). At 30 mm depth its values are very similar for each method. However, for greater depths the contrast provided by PWI is roughly 2.5 dB and 1.5 dB better that for BFR and STA respectively.

V. Conclusions

The comparison of the resulting images indicates the advantage of the synthetic aperture schemes over the classical approach. Due to the dynamic focusing in transmit, the STA and the PWI are expected to provide better resolving power and so they do. The FWHM for the BFR is roughly 40% higher than in case of the PWI. Also in terms of the sidelobe level the classical beamforming is far behind the synthetic aperture techniques (-15 dB vs -25 dB and -30 dB for BFR, PWI and STA respectively). Moreover, below the focal depth the BFR suffers from a rapid decline of the SNR equal to -4 dB/cm while for the synthetic aperture schemes the decrease is only -1.5 dB/cm. Finally, the BFR also provides the worst CNR. It must be noted that most of the BFR's drawbacks can be overcome by a multiple focusing, however it significantly reduces the frame-rate, which limits the utility of this technique. In contrast to the classical approach the synthetic aperture techniques provide better and more uniform imaging quality while maintaining the ability of working at very high frame-rates.

The choice among the PWI and the STA is difficult as the performance of both techniques can be optimized for given conditions through adjustment of their parameters. However, based on our results we can conclude that the PWI seems more useful since it provides higher CNR at deeper regions than the STA, thus allows for better penetration.

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