3-D IMAGING METHODS USING 2-DIMENSIONAL PHASED ARRAYS BASED ON SYNTHETIC FOCUSING TECHNIQUE

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Abstract: Two methods for real-time 3-D ultrasound imaging using 2-D phased arrays based on synthetic focusing technique are presented, in which ultrasound waves are transmitted from each column elements and received by all elements of the 2-D array. First, a synthetic focusing technique using defocused transmission (CSF-DF) is proposed, which can dramatically improve the volume rate since one volume can be obtained by only N transmit/receive events where N represents the number of element columns. Secondly, a synthetic focusing technique using conventional phased array transmission (CSF-PA) is proposed, which can dramatically improve the resolution. Using this method, all scan lines within a frame of interest can be obtained by employing two-way dynamic focusing and conventional receive dynamic focusing in the transversal and longitudinal directions, respectively.

Introduction

3-D ultrasound imaging methods based on two dimensional beam steering with 2-D phased arrays (2D-PA) should support much larger number of active channels than 1-D phased array imaing, which forces to use a very expensive and bulky beamforming hardware [1][2]. Furthermore, some additional efforts must be made to reduce the number of wires between the 2-D array and the system, which include putting highly integrated beamforming circuits inside the probe.

In spite of the huge increase in system cost and complexity, it takes 2 seconds for 2D-PA imaging with conventional single-beam based scanning method to produce a volume of interest consisting of 64 image slices with a view depth of 20cm, each formed with 128 scan lines.

To overcome these limitations, a 3-D imaging method using cross arrays was proposed previously for fast volumetic scanning [2]. In this method, a 1-D transmit array(or a vertical array) placed along the elevation direction is used to project fan beams with a wide width in the transversal direction, of which the direction in the longitudinal direction is incremented in a succession of firings to scan a volume of interest. This method, however, suffers from low resolution since one-way focusing is employed in both the longitudinal and transversal directions.

We applied the core idea of realtime volumetric scanning with a cross array to realtime 3-D imaging with 2-D phased arrays, which will be called 2-D phased array focusing method with defocusing transmission scheme (2D-DF). In this method, as shown in figure 1, ultrasound waves are transmitted from all the array elements for each firing to produce a beam plane which is focused at a fixed depth along each of the prespecified longitudinal directions and spread in the transversal direction to cover the required view angle in that direction.

To do this, each column of the 2-D array is given the conventional focusing delays in the longtudinal direction and defocusing delays in the transversal direction. The pulse echo signals for each firing are received and recorded at all array elements, which are then processed to produce all the scan lines forming a slice of image directed in a specific longitudinal direction. Consequeltly, this method can produce one whole image slice per one T/R event. In the longitudinal direction, each beam is formed by employing fixed focsuing on transmit and receive dynamic focusing on receive. In the transversal direction, each beam is not focused on transmit and focused dynamically on receve.

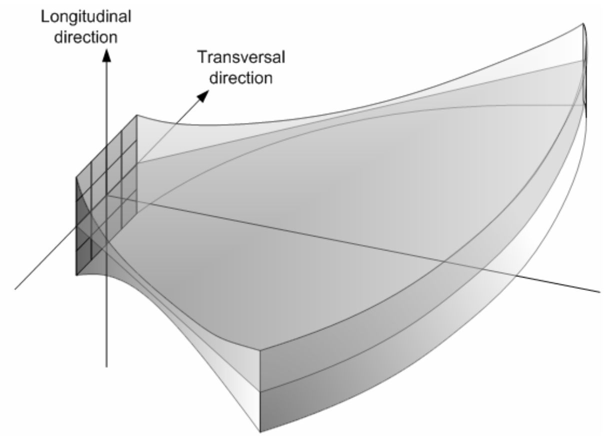

Figure 1: 2D-DF imaging scheme with one T/R event

To improve the performance of 2D-PA and 2D-DF imaging, we propose two 3-D ultrasound imaging techniques using 2-D phased array transducers based on synthetic focusing method. Computer simulation results show that one method can provide two-way dynamic focusing in the transversal direction, which can be used for high resolution 3-D imaging, and the other one provides a very high volume rate for realtime 3-D imaging.

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Methods

First, a combined synthetic focusing method employing defocused transmission (CSF-DF) scheme is proposed to achieve a very high speed volumetric imaging. In this method, as shown in figure 2, defocused beams in the vertical(longtudional) direction are transmitted successively from each column of 2-D array. Each transmitted beam will be spread in the horizontal(transversal) direction because of the narrow width of each column. The resulting pulse echoes are recorded at all elements. Using these received echo signals for all firings, all the scan lines within a volume of interest can be obtained by employing two-way dynamic focusing using synthetic focusing technique in the transversal direction and one-way dynamic focusing in the longitudinal direction. Note that a whole volume of interest can be scanned after N T/R events where N represents the number of columns (or rows). This method also does not focus the transmit beam in the longitudal direction while dynmic focusing is employed on receive. In addition, it would suffer from motion artifact since each imaging point is formed using data received from N firings. Thus, this method should be used either for slowly moving objects or with proper motion compensation method [3].

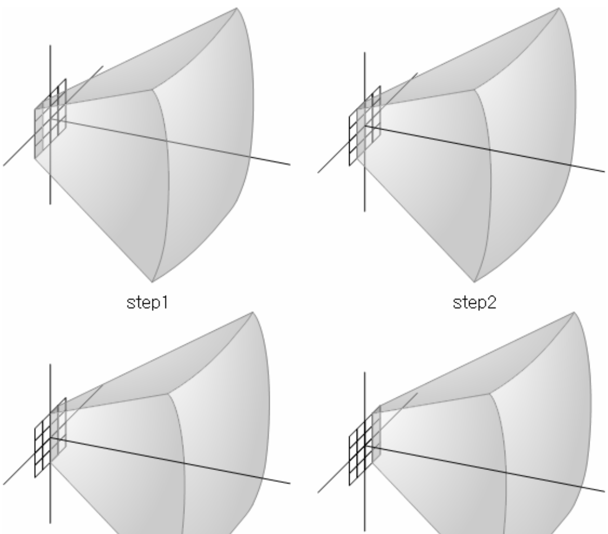

Figure 2: Transmission steps of CSF-DF imaging scheme

The second method uses a combined synthetic focusing technique with focused transmission scheme as in conventional phased array imging (CSF-PA), of which each column of the array is fired successively and and the resulting pulse echoes are received by all elements. After firing all columns, a slice image is formed with beams focused dynamically in the transversal direction on both transmit and receive using SF technique. In the longitudinal direction, each beam is focused at a fixed depth on transmit and dynamically on receive. Therefore, this method povides the best spatial resolution that can be obtained at a volume rate comparable to that of the conventional 2D-PA scheme.

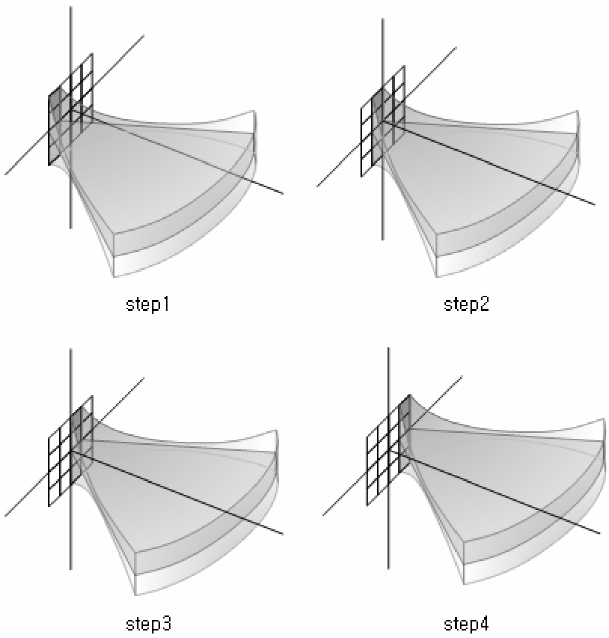

Figure 3: Transmission steps of CSF-PA imaging scheme

Results

Computer simulations were performed to verify the proposed methods using a 64×64 phased array with the center frequency of 3.5MHz and element pitch of $\lambda/2$. Figures 4 and 5 show the CW beam patterns in the transversal and longitudinal directions, respectively, at 40mm(a), 80mm(b) and 120mm(c). The transmit focal point is at 80mm in case of 2D-PA. In figure 4, CSF-DF and CSF-PA provide better spatial resolution than 2D-PA: The impovement will increase with the distance between the imaging depth and transmit focus. To scan a volume of interest with 64 slice images, each consisting of 128 scan lines, CSF-DF requires only 64 T/R events, whereas 2D-PA and CSF-PA require 8192 and 4096 events, respectively.

Table 1: Performance Comparison

Scheme	Number of T/R events (volume rate)	Focusing Technique (Resolution)	
		transverse	longitude
2D-PA	8192 (0.5 v/s)	CF	CF
2D-DF	64 (64 v/s)	OF	CF
CSF-DF	64 (64 v/s)	SF	OF
CSF-PA	4096 (1 v/s)	SF	CF

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Table 1 summarizes the characteristics of four imaging methods in terms of scanning speed and spatial resolution, conventional focusing (combinaiton of fixed focsuing on trasnmit and dynamic focusing on receive), one-way dynamic focusing (no transmit focusing and receive dynamic focusoing) and synthetic focsing (dynamic focusing on both transmit and receive) are denoted as CF, OF and SF, respectively. The number of T/R events was calculated for the case where multi beam focusing is not employed. It should be noted that the number of T/R evenets of each method can be reduced by using techniques such as multi beam focusing and sparse array imaging technique.

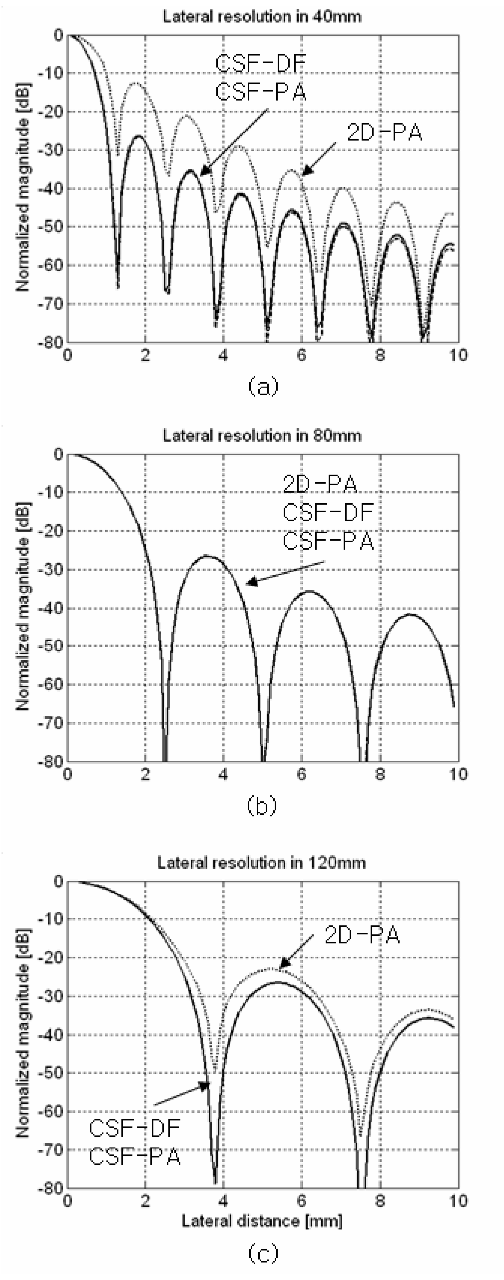

Figure 4: Comparison of transversal beam patterns of 2D-PA, CSF-DF and CSF-PA at 40mm(a), 80mm(b), and 120mm(c). Transmit focal depth of 2D-PA is 8cm

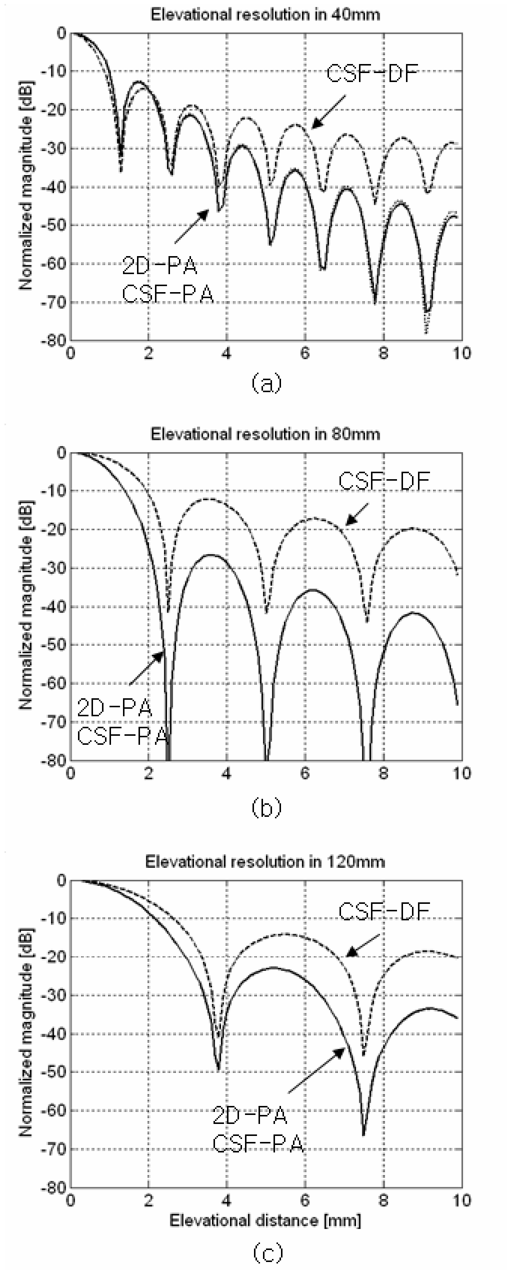

Figure 5: Comparison of the longitudinal resolutions of 2D-PA, CSF-DF and CSF-PA at 40mm(a), 80mm(b), and 120mm(c)

It is obvious that among the four methods CSF-DF and CSF-PA are best solutions for high speed imaging and high resoultion imaging, respectively. As can be seen from figure 4, CSF-DF and CSF-PA have the same lateral beam patterns which are better than those of 2D-PA except at its transmit focal depth (panel (b)) where three methods have the same beam pattern. In the longitudinal direction, 2D-PA and CSF-PA should have the same beam pattern as shown in figure 5. CSF-DF method exhibits higher sidel lobes because transmit focusing is not performed in the longitudinal direction. Therefore, methods for reducing the side lobe levels of one-way focusing should be investigated. It will be also instructive to compare experimentally the image quality of two methods: one is using fixed focusing on both transmit and receive (as in elevational fousing with 1-D phased array) and the other receve dynamic focusing while unfocused beam is used on transmit (as in CSF-DF case).

Conclusions

In this paper, we proposed 3-D ultrasound imaging methods using 2-D phased arrays based on synthetic focusing technique. Computer simulation results show that CSF-DF and CSF-PA provide two-way dynamic focusing in transversal direction. Moreover, CSF-DF provides a very high volume rate that is tens or hundreds of timese faster than the conventional 3-D imaging with a 2D phased array..

Because the proposed methods are based on synthetic focusing technique, however, they are sensitive to motion artifacts induced by movement of the transducer and the target object. But, since the proposed methods require a small number of ultrasound transmit-receive events, motion artifacts can be ignored for imaging of stationary or slowly moving objects. The proposed methods can also be used for achieving high speed 3-D imaging of fast moving objects, in conjunction with efficient motion compensation schemes. Moreover, CSF-PA method can be used to improve not only spatial resolution but also volume rate by reducing the number of T/R events with sparse synthetic focusing techniques.

Further researches are required to mitigate some drawbacks of the proposed methods.

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