Fast High-Resolution Ultrasound Microvessel Imaging with Null Subtraction Imaging-based Beamforming

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***Abstract*— Recently, microvessel imaging at super resolution using contrast agents has been successfully demonstrated. However, the computational costs associated with the processing is extremely high. To overcome some of the computational issues, new techniques for generating high-resolution microvessel images with contrast MBs are warranted. One computationally inexpensive technique to realize high-resolution microvessel imaging is to use null subtraction imaging (NSI)[1]. NSI uses nulls in the beam pattern to produce images at much higher apparent lateral resolution and is especially suited for sharpening ultrasound images of specular scatters like MBs. In this study we acquired 1000 frames of ultrasonic data of chicken embryo with microbubble as contrast agent inside and utilized NSI to attain image with improved spatial resolution compared with traditional delay and sum image.**

Keywords—NSI, DAS, Microbubble, Super Resolution

I. Introduction

Ultrasound localized microscopy (ULM) [2], [3], [4] and methods for improving ULM [5] have been proposed, which demonstrated its ability to achieve subwavelength resolution. By deconvolving the point spread function (PSF) formed by microbubbles, ULM could determine the center of the PSF, which is the position of microbubble to within micrometers of spatial resolution. In this way individual microbubbles could be isolated and tracked according from the ultrasound signal. However, this process is highly computational and expensive in terms of localizing each microbubbles. Recently, Null subtraction imaging (NSI) has been proved to be a computationally inexpensive method to improve the apparent lateral resolution in B-mode imaging by performing delay and sum (DAS) beamforming with three different apodization and subtracting the nulls in beam pattern to narrow the receive beamwidth. The computation cost is only three times of traditional DAS beamforming. In this study, we used NSI to replace DAS beamforming in power Doppler of ultrafast microvessel imaging with contrast microbubbles (MBs). We shows improved spatial resolution with the NSI technique compared to traditional DAS beamforming while maintaining much lower computational cost compared to ULM imaging.

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II. Methods

A. Data Acquisation

Ultrasonic data were acquired from the brain of a chicken embryo using a Verasonics Vantage 256 system and a L22-14 array probe (both from Verasonics Inc.). The data set included 1000 frames acquired at 1000 Hz post-compounding PRF (10-angle compounding). The transmit voltage was limited to 5V in order not to destroy MBs. All frames were interpolated by a factor of 10 in the lateral dimension and a factor of 4 in axial dimension.

B. Post Processing

After acquiring the ultrasonic data, a custom Matlab script was used to process the data and construct the microvessel image. The specific steps are listed below:

1) Singular value decomposition (SVD)-based clutter filter was used to remove the stationary tissue signal.
2) DAS beamforming was performed on 250 frames of the filtered data using three different apodization schemes on subapertures of the array. The three apodization schemes include the DC1 (DC offset 1), DC2 (DC offset 2) and ZM (zero mean), which were applied separately to each steering angle used for compounding.
3) Coherent compounding was then applied to generate three sets of receive focused data, each corresponding to an apodization scheme.
4) Envelope detection was then applied to each frame after coherent compounding.
5) The image intensity of the filtered frames was accumulated for each apodization set over 250 frames, which results in a mapping of the MBs through the microvessel in the field of imaging. The 250 frames were chosen to reduce blurring caused by tissue motion.
6) Finally, we applied the NSI algorithm of subtracting the ZM image from the DC1 and DC2 images to get the final image.

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Figure 1 shows above steps in a flow diagram manner.

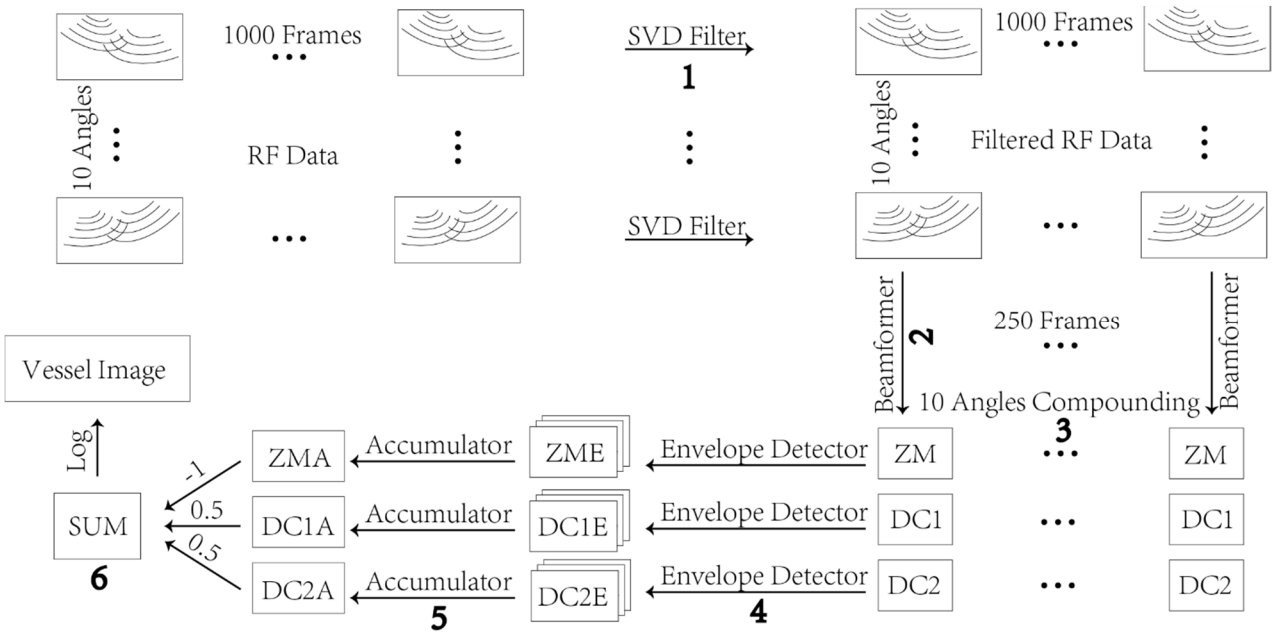

Fig.1 Post processing flow

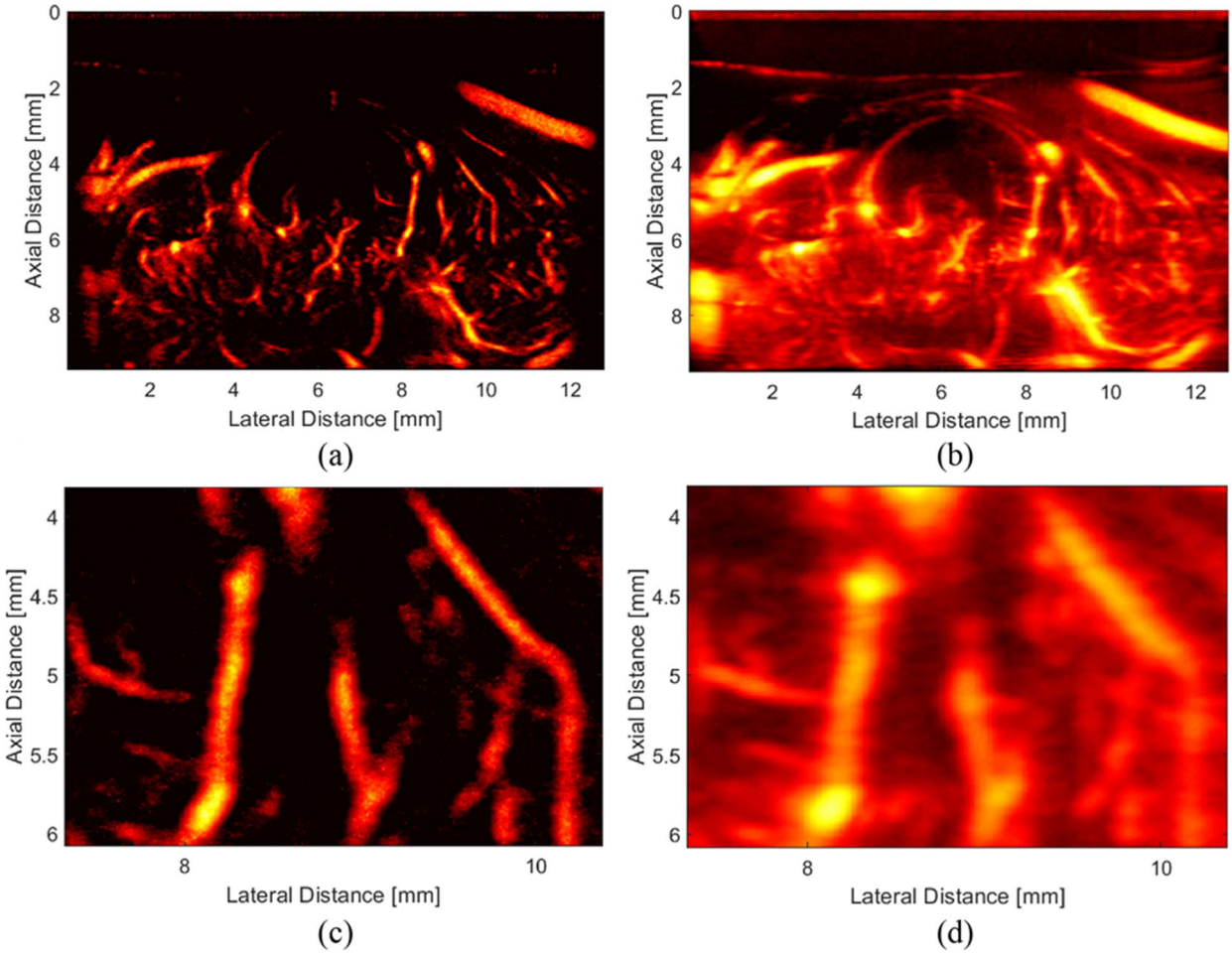

Fig.2 Comparison of NSI with DAS vessel image. (a) NSI image (b) DAS image (c) Zoomed NSI image (d) Zoomed DAS image

III. Results

Figure 2 shows a side by side comparison of a power Doppler image when using MBs of a chicken embryo created with NSI (left) and created with traditional DAS (right). Each image is displayed with a 60 dB dynamic range. From the images, it can be observed that the spatial resolution of the NSI image is markedly improved compared to traditional DAS. The width of the vessels were narrowed in the NSI image and some vessels that could not be differentiated in the traditional DAS power Doppler image are now separated in NSI image, which is shown in the zoomed version in Fig.2. The comparison of NSI and DAS image's cross-section of a vessel is shown in Fig.3.

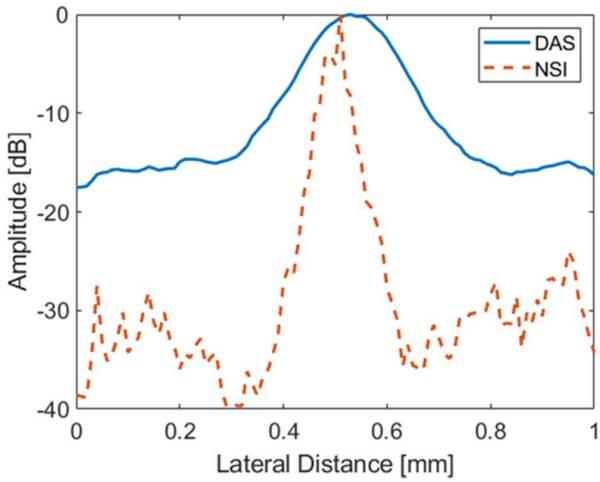

Fig.3. NSI and DAS image's comparison of cross section of a vessel

IV. Conclusion

The computational cost of NSI is approximately three times the cost of DAS, which indicates that NSI can be implemented in real time. In comparison, using traditional super resolution microvessel imaging, processing to isolate bubbles, deconvolving the PSF from each bubble and tracking the resulting bubble point targets takes up to an additional 10 hours of computation. Therefore, NSI offers a cost-effective and viable alternative approach to achieve high-resolution microvessel imaging with the presence of MBs.

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