The Efficiency of Applying Compressed Sampling and Multi-Resolution into Ultrasound Tomography

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Abstract

The limitations of diagnostic ultrasound techniques using echo information has motivated the study of new imaging models in order to create additional quantitative ultrasound information in multi-model imaging devices. A promising solution is to image sound contrast because it is capable of detecting changes in diseased tissue structures. Ultrasound tomography shows speed-of-sound changes in propagation medium of sound waves, this technique is primarily used for imaging cancer-causing cells in women breast. The Distorted Born Iterative Method (DBIM) based on first-order Born approximation is an efficient diffraction tomography approach. The compressed sensing technique is utilized for DBIM to obtain the high-quality ultrasound image. However, the image reconstruction process is quite long. In this paper, we proposed an approach to enhance the imaging quality and to reduce the imaging time by applying the compressed sensing technique along with the multi-resolution technique for the DBIM. The simulation results indicate that the imaging time is 33% reduced, the imaging quality is 83% improved.

Distorted Born Iterative Method - DBIM

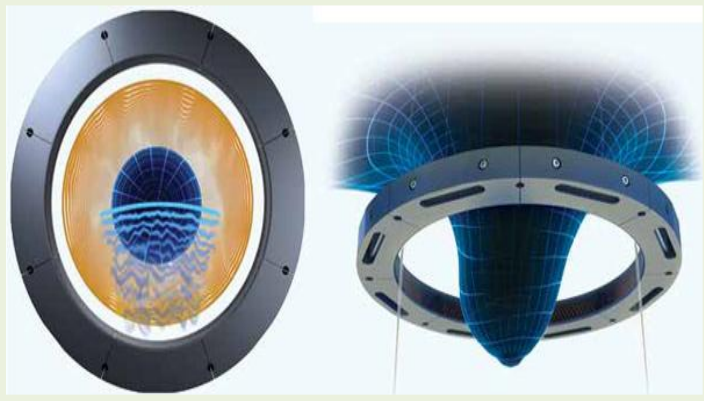
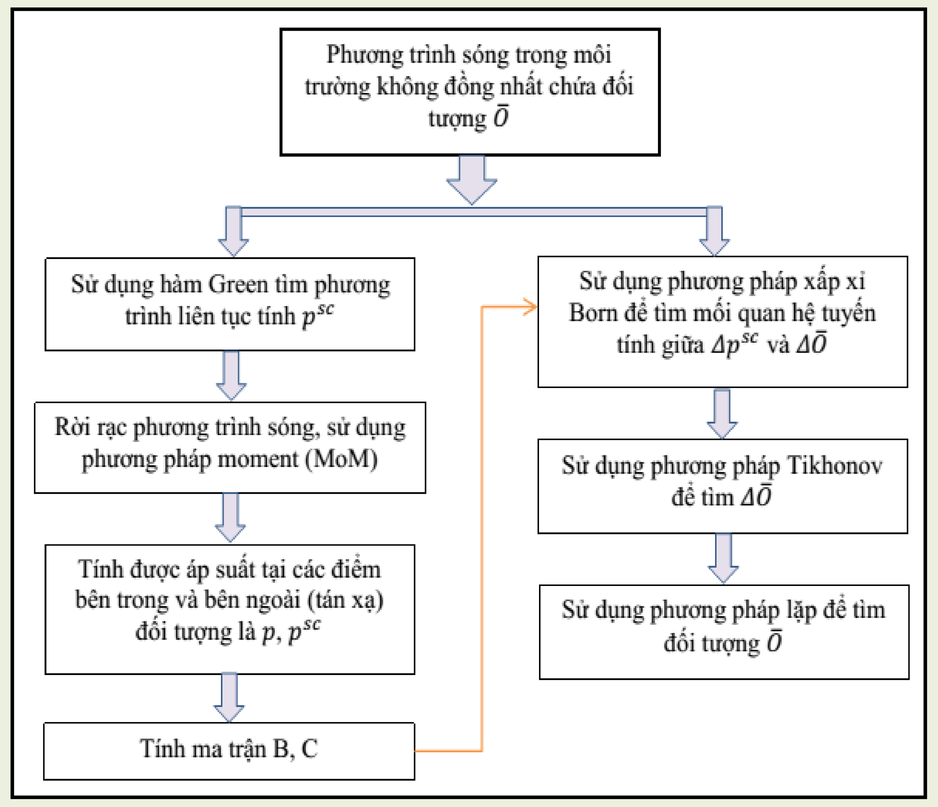


Fig. 1. Ultrasound Imaging System



PT sóng hệ thống: $\left(\nabla^2 + k_0^2(r)\right)p(r) = -O(r)p(r)$ với $O(r) = k(r)^2 - k_0^2 = \omega^2\left(\frac{1}{c_r^2} - \frac{1}{c_0^2}\right)$

Áp suất âm tổng (Hàm Green): $p(r) = p^{inc}(r) + p^{sc}(r) = p^{inc}(r) + \iint O(\vec{r'})p(\vec{r'})G_0\left(\left|\vec{r} - \vec{r'}\right|\right)d\vec{r'}$

Áp suất của các điểm bên trong đối tượng: $\bar{p} = \left(\bar{I} - \bar{C}.D(\bar{O})\right)p^{inc}$

Áp suất của các điểm bên ngoài đối tượng: $p^{sc} = \bar{B}.D(\bar{O}).\bar{p}$

Độ chênh lệch áp suất tán xạ (Xấp xỉ Born): $\Delta p^{sc} = \bar{B}.D(\bar{p}).\Delta\bar{O} = \bar{M}.\Delta\bar{O}$

Giải bài toán ngược (PP Tikhonov): $\Delta\bar{O} = \arg\min_{\Delta\bar{O}}\left\|\Delta\bar{p}^{sc}{}_t - \overline{M_t}\Delta\bar{O}\right\|_2^2 + \gamma\|\Delta\bar{O}\|_2^2$

Hàm đối tượng (PP Lặp): $\bar{O}^n = \bar{O}^{(n-1)} + \Delta\bar{O}^{(n-1)}$

The Proposed DBIM-CS-MR Method

The proposed DBIM-CS-MR method consists of three stages. The first stage is reconstruction process with a raw meshed integration area which has the size of $N_1 \times N_1$ using the DBIM-CS. We can easily obtain the convergence after $N_{1\text{-iter}}$ iterations. The obtained result at this stage is the average background value of the object. In the second stage, the interpolation is applied to the obtained result of the first stage from the size of $N_1 \times N_1$ to the size of $N_2 \times N_2$. Finally, the obtained result of the second stage is continuously reconstructed using the DBIM-CS with the desired size of $N_2 \times N_2$ and $N_{2\text{-iter}}$ iterations.

Compressed sensing (CS), which is introduced by Candes and Tao and Donoho in 2006, could acquire and reconstruct sparse signals at a rate lower than that of Nyquist. Random measurement approach in the detection geometry configuration is proposed in. A set of measurements of the scattered field is performed using sets of receiver's random positions. This method can reduce the computational complexity and improve the quality of the reconstruction of the sound contrast..

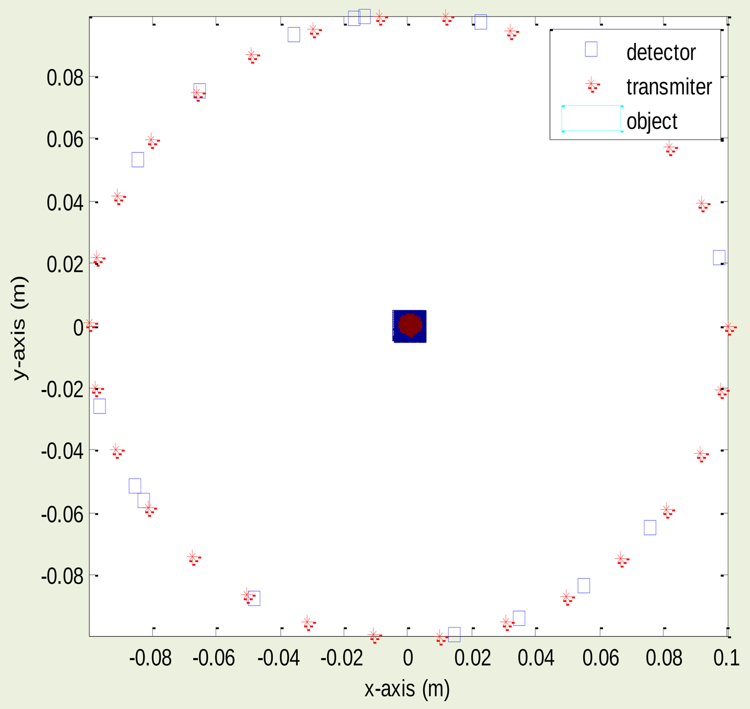


Fig. 2. Proposed configuration of transmitters and detectors using linear transmitter locations and random detector locations

Simulation parameters: Incident frequency f = 1 MHz; Number of transmitters N_t = 29; Number of receivers N_r = 15; Total number of iterations N_{sum} = 4; Number of pixels of object N = 22; N_1 = 11; N_2 = 22; $N_{1\text{-iter}}$ = 2; $N_{2\text{-iter}}$ = 2; Scattering area diameter = 7.3 mm; Sound contrast 7%; Gaussian noise 10%; Distances from transmitters and receivers to the center of the object are 100 mm and 100 mm, respectively.

The incident pressure for a Bessel beam of zero order in two-dimensional case is

$$\bar{p}^{inc} = J_0(k_0|r - r_k|)$$

where J_0 is the 0[th] order Bessel function and $|r - r_k|$ is the distance between the transmitter and the k[th] point in the ROI.

The error used to evaluate the performance of the proposed method is

$$\varepsilon = \frac{1}{V \times W}\sum_{i=1}^{V}\sum_{j=1}^{W}\frac{\left|m_{ij} - \hat{m}_{ij}\right|}{\left|m_{ij}\right|}$$

where m is a V×W original image and $\hat{m}$ is the reconstructed image.

Simulation and results

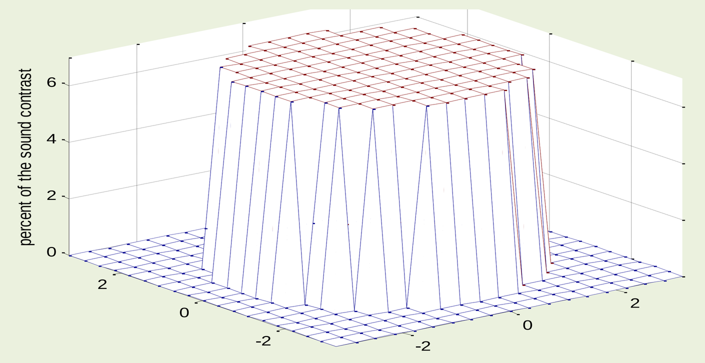


Fig. 3. Ideal object function

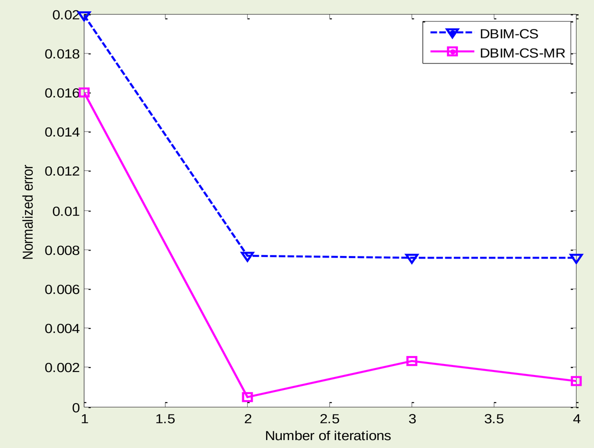


Fig. 4. Normalized error comparison of the conventional and proposed methods

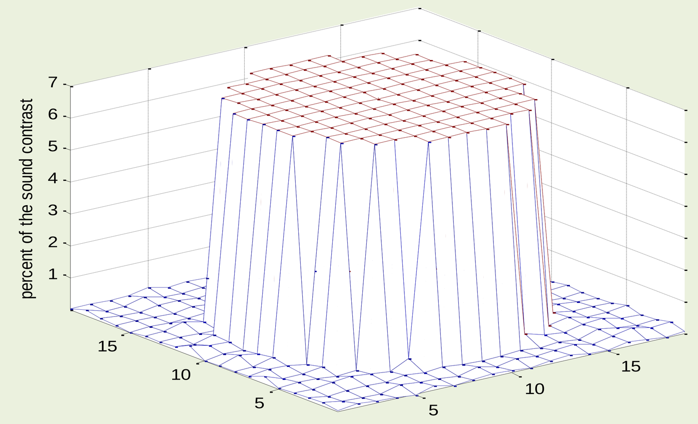


Fig. 5a. The reconstructed result of the DBIM-CS method after N_{sum} iterations

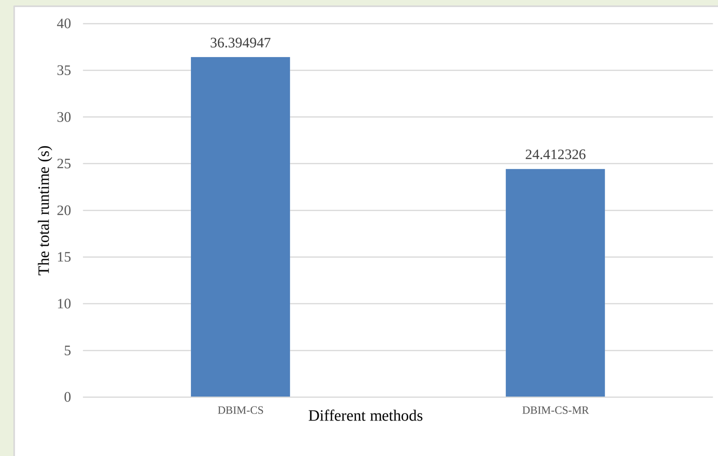


Fig. 6. The chart of the total runtime corresponding to different methods after N_{sum} iterations

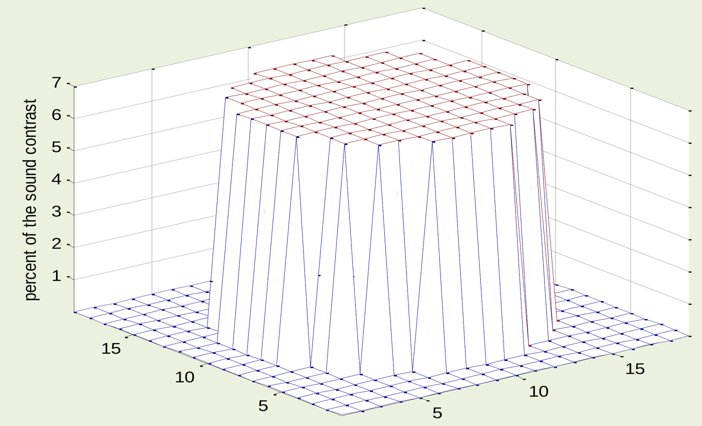


Fig. 5b. The reconstructed result of the DBIM-CS-MR method after N_{sum} iterations

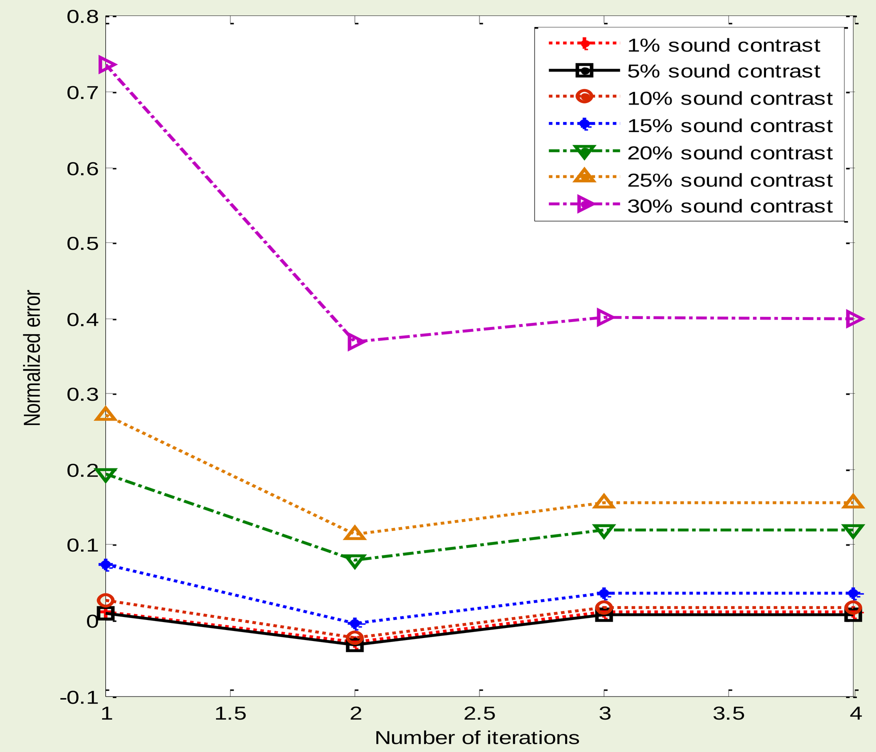


Fig. 7. The normalized error of the proposed method after N_{sum} iterations corresponding to different values of sound contrast

Conclusions

Inverse scattering utilizing DBIM is a popular technique which can be used to resolve structures which are smaller than the wavelength of the incident wave, as opposed to conventional ultrasound imaging using echo method. This paper has successfully applied compressed sensing technique and multi-resolution technique in order to improve the quality of the image reconstruction. Simulation scenarios of sound contrast reconstruction were conducted to prove the good performance of this method.