Time Reversal Reconstruction Algorithm for Photoacoustic Imaging

Snigdha Dange*

Department of Electronics and Communication Engineering, Visvesvaraya National Institute of Technology

*Corresponding author

doi: https://doi.org/10.21467/proceedings.114.53

Abstract

This is the algorithm of time reversal reconstruction where a model of numerical of the problem of forward is functioned towards backwards in time of acoustics. There is an inventive imaging technique to image biomedical tissues which is also called photoacoustic imaging. In this paper, for photoacoustics imaging a time reversal reconstruction algorithm is proposed which is based on method of optimized support vector machine (SVM) interpolation, (PSO) particle swarm optimization. The images which are reconstructed from the algorithm are more exact than those of the process of interpolation of cubic convolution, interpolation of nearest neighbor and linear interpolation, whereas the numerical results are shown based on algorithm of time reversal, where it can provide quality with enough huge imaging resolution by usage of precisely less times of scan or measurements.

Keyword: Time Reversal Reconstruction, Photoacoustic Imaging, Particle Swarm Optimization, Support Vector Machine

1 Introduction

Photoacoustic Tomography is reported as the “minimal prohibitive” algorithm of imaging on the reference that it depends hardly on any presumptions than many other algorithms of reconstruction of imaging[4,5]. The reconstruction of image at each time step progress would be considered as ongoing a model of numerical of forward problem backwards in domain of time, so that a Dirichlet boundary condition can enforce measured time-varying pressure signals at their recorded positions which is called reconstruction method of time reversal. In Photoacoustic imaging there is combination of ultrasonic wave and electromagnetic interconnection, which provides relatively deep freckel-free imaging at resolution of high ultrasonic with high electromagnetic contrast[1,2]. Various reconstruction methods, such as inversion of the linear Radon transform, Fourier transform, filtered backprojection, time reversal, alternative algorithm, , and delay and sum beamforming, have been produced under various contrasting presumptions and estimation [3]. Otherwise, various measurement of phantom will guide to various different final shapes of artifacts.

There can be a significant blurring in the reconstructed images if the detectors points sparse array is used to collect the discrete measurement rather than a continuous surface area due to which the forcing of time reverse boundary condition change will no longer last. This problem was solved by Treeby and Cox[6] where they developed reconstruction of image or reshaping using integrated or interpolated sensor data. Interconnections can be avoided by inserting data which is recorded into a continuous surface area rather than measuring the discrete surface area within the grid of space used for reconstruction . The edges of the image which is reconstructed are very sharp and the magnitude showed improved results. When Treeby and Cox[7] used the compulsory time to change the boundary condition of reversal of time to capture the artifacts objects in the outcome of final image, and by diminishing the information, or applying the boundary condition of threshold of adaption, this capturing of artifact can be attenuated to a certain level. In this paper, the main concern is the method where the elimination of artifacts and interlinkage of

Proceedings DOI: 10.21467/proceedings.114; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-8-8

reconstruction of image uses algorithm of "time reversal". There has been generation continuous area which corresponds spatially to the primary measurement surface of Cartesian via interpolation of advanced amalgam algorithm. So, it shows that there is reduction in artifact, improvement in the magnitude of acoustic and in the SNR ratio through partial correction for the non-continuous aperture by experimenting with the suggested algorithm.

2 Theory

2.1 Acoustic Propogation Theory in PAT

From the initial value problem the photoacoustic wave equation can have formula in lossless medium of acoustic for photoacoustic tomography .

Forward problem for photoacoustic can be written as-

$$\left[\frac{\partial^2}{\partial t^2} - c(x)^2 \rho(x) \nabla . \left(\frac{1}{\rho(x)} \nabla\right)\right] p(x,t) = 0, \qquad (1)$$

Where the conditions of initial procedure are presented by

$$p(x,t)|_{t=0} = p_0(x),$$

$$u(x,t)|_{t=0} = \frac{\partial p}{\partial t}|_{t=0} = 0, \qquad (2)$$

Where $p(x,t)$ is the pressure of acoustic for the given time $t \in R^+$ and pointed dot $x \in \ \Omega \subset R^n$ in the internal area of imaging Ω, $u(x,t)$ is the velocity of acoustic particle, $c_0(x)$ is the speed of sound and $\rho(x,t), \rho_0(x)$ are the acoustic and ambient densities respectively.

2.2 Time Reversal Image Reconstruction

PAT signals have origination from absorption of optical. The generation of signal of photoacoustic process can be presented in following steps: (1) light absorption of an object, (2) the energy of optical which is absorbed is transformed into heat and there will be generation in a rise of temperature , and (3) expansion of thermoelastic takes place which results in the emission of acoustic waves. include hemoglobin, melanin, and water contains typical endogenous tissue chromophores which are typical optical absorbers.

In PAT image reconstruction so the main concern is to approximate the distribution of initial pressure $p_0(x)$ in the inner side of region of imaging Ω where the calculation which measures $p(x,t)$ is given on surface S of measurement of arbitrary . By using the measurements which are recorded and stored, $p_m(x_S,t)$ of the pressure of acoustic, $p(x_{S,}t)$ the estimation of time reversal imaging is achieved over an surface of arbitrary $x_S \ \in S$ for time $t = 0 \ to \ T$. So , zero is set for initial pressure in (2), producing

$$p(x,t)|_{t=0} = 0,$$

$$u(x,t)|_{t=0} = 0$$

$$p(x_{S,}t) = p_m(x_S, T-t) \qquad (3)$$

From the equation, the pressure is obtained from t=0 to T ; at the same time in the imaging field , the computation of the variable t of reverse-time from t=0 to T is also achievable. The the acoustic pressure performs the reconstruction time histories which is measured on S for t =0 to T in order of backward of time where it can be enforced the time-changing condition of boundary of Dirichlet on $\hat{S}$ within a propagation of numerical of acoustic prototype. Here, $\hat{S} \subset \hat{\Omega}$ and both $\hat{S}$ and $\hat{\Omega}$ are in identicals of silico to the present world S and Ω .

For production of additional waves there should be no intereference of the time reversed waves as ϱ and c can vary broadly during the time reversal reconstruction to reproduce the original wave field. There are vestiges of time reversed of the dispersed waves which are extra also called vestigial waves. Artifacts in the final PAT image can be constituted by persisting among the domain of computational . The artifacts objects and interconnection which can be broadly wiped out by interpolating the information which is recorded in the form of measured values of continuous area surface within the grid of area of space mainly applied for the reconstructed image so that it can improve the reconstruction result of the discontinuous aperture. As an amalgamation of optimization algorithm of interpolation, convergence of higher rate and precision of optimization can be gained by algorithm of interpolation which is optimized by SVM in PSO, which has been used to develop a surface which is continuous that is broadly analogous to the actual surface of measurement of Cartesian via interpolation is used to solve the issue.

3 Algorithm of PSO Optimization by SVM Interpolation

Optimization search processes the extract of the (SVM) selection of instructing parameter[8]. In the processing of interpolation, such as the correctness of fitting and the capability of generalization, the selection of the function of nuclear, parameter of nuclear, the coefficient of penalty, and other various parameters has direct relation to the index of prototype of the training of the SVM in the parameter optimization algorithm [9].The search for the solution of optimal through the alliance of the specifically individual particles is an optimization tool which is based on iteration . Global optimization has given the algorithm a strong capability. The search for the location of space for a bird is the imitation for the PSO algorithm to solve the problem of optimization . Here the "particles" are the birds in the space. To have closeness to the optimal point, each and every particle balance its path of flight correspondingly which is build on the experience of flight individually . According to the flight objective function various particle differ in location, speed and fitness individually. By tracking two "extreme values", it adjusts the flight path. Individual extremum is one of the extreme value which refers particle optimal solution on its own. The another one is the extremum of global, which refers to the whole answer of swarm optimal.
When the two extreme values are discovered, there in updation of particles in their speed and locations as follow

$$v_{id}(t+1) = wv_{id} + c_1 rand_1(i)\big(p_{id}(t) - x_{id}(t)\big) + c_2 rand_2(i)(p_{gd}(t) - x_{id}(t)) \quad (4)$$
$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1)$$

where w is the weight of inertia; t is the time of ongoing of evolution iteration of reversing; $i = 1,2,\ldots\ldots,m, d = 1,2,\ldots\ldots,n$; $rand_1(i)$ and $rand_2(i)$ are numbers which are random and also are separated in the intermission of [0,1] m is the magnitude of swarm; c_1 and c_2 are the factors of acceleration; $x_{id}(t)$ is the component of d-dimension of the area of location of the tiny particle of ith position in the iteration of t; $v_{id}(t)$ is the component of d-dimension of the velocity of the particle in ith position in the iteration of t; $p_i = (p_{i1}, p_{i2}, \ldots, p_{in})$ is the extreme value of individual ; $p_{id}(t)$ is the component of d-dimension of the best particle place in ith position; $p_q = (p_{q1}, p_{q2}, \ldots, p_{qn})$ is the extreme value of global; $p_{gd}(t)$ is the component of d-dimension of the best specific place containing swarm. Discussion about the difficulty of optimization of the factor of penalty c , parameter of insensitive γ, and the parameter of nuclear σ lead to use the PSO algorithm to solve the problem of optimization . The progress of Particle Swarm Optimization-SVM Method is represented in Figure 1. The Variables of C ,γ and σ are connected with practical problems and samples which are learning. The degree of threshold is controlled by penalty factor C when prototypes are miscategorized and an adjustment between error of training and prototype obstacle is achievable. The higher precision of fitting is required when C is larger. It takes a longer time and makes training difficult. But it will lower the fitting precision when C is smaller. The generalization capability of the system will be deteriorated by too large or too small value of C . The latter is called "less learning." and the former is called "overlearning" The regression model's sensitivity of the noise is reflected by insensitive parameter γ included in variable of input. The fitting accuracy of lower prototype and difficulty is also subject to overfit when γ is larger . The parameter of nuclear σ constitutes the MSE (mean square error) of function of Gaussian and is the width of function in direction of parameters independently. The function of kernel has good fitting, when σ is smaller. But it will decompose the ability of generalization. So, by applying the PSO algorithm we can get solution to the problem of optimization by discussing the difficulty of optimization of the factor of penalty c , parameter of insentive γ , and the parameter of nuclear σ .

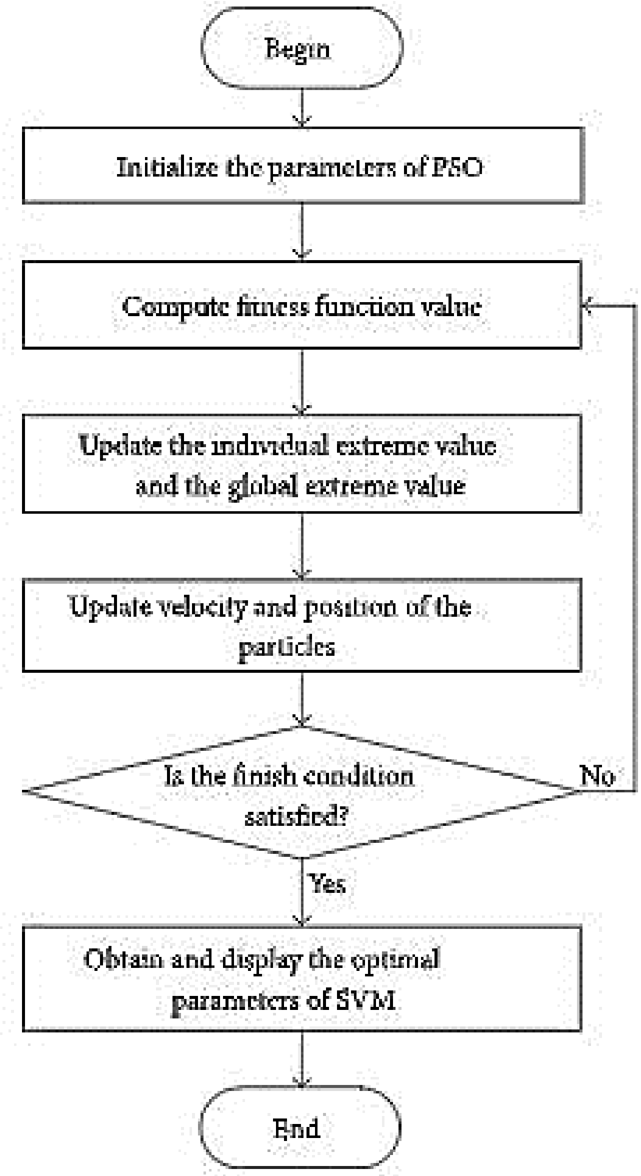


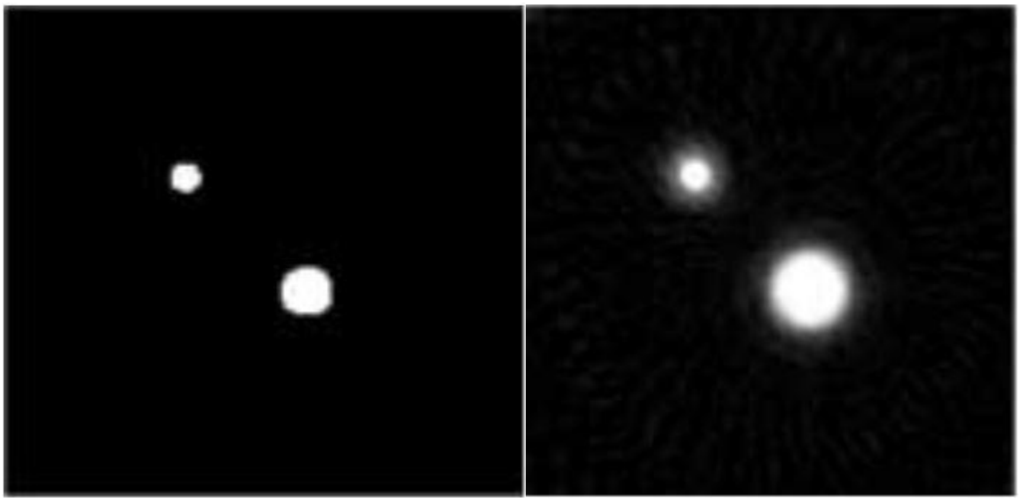
Fig. 1. Specification Process of PSO-SVM Method

PSO algorithm cannot solve the solution data in space directly in the process of SVM interpolation. So to solve the optimization problem, the specific way is to code it and transform it to the structure of particle string of space. There are 3 optimization parameters in this procedure called (c,γ,σ) where they are the dimension of the particle location. The m 3d particles x_{id} is the represention of the initiate location of the particles swarm, where there is usage of real value encoding and there is random generation as reported by the parameters interval of optimal. The number which is random v_{id} generation is the speed of initial in [0,1] . There appears an upcoming complication of limit of optimization of parameter of speed and area of locations of the particle swarm. So, for the three parameters there should be normalized mapping process before the optimization process. And after the updating or renovating, original scope will achieve the inverse normalized process. In the process of iterating, procedure is set for algebra of fixed evolution. In the procedure of solving, in each generation there will be comparison between the maximum value and the fixed value; the process will get done when the 2 values come up with an final evaluation.

4 Results

4.1 Time Reversal Reconstruction Algorithm

We have taken a phantom which is simulating tumor tissue for the initial pressure distribution with a 256 × 256 grid of pixel which is shown in Figure 2(a). There is reconstruction of the PAT phantom by using the conventional time reversal algorithm , and the outcome is shown in Figure 2(b). Due to the discontinuous boundary condition there has been reconstruction of PAT image which has been significantly blurred, and vestigial waves have caused some artifacts. Figure 3 The figure shows there is a large amplitude gap between a pressure outline which is initial and the pressure which is reconstructed conventionally.



Phantom image of PAT:Fig. 2(a). distribution of initial pressure; 2(b). time reversal of conventional reconstruction .

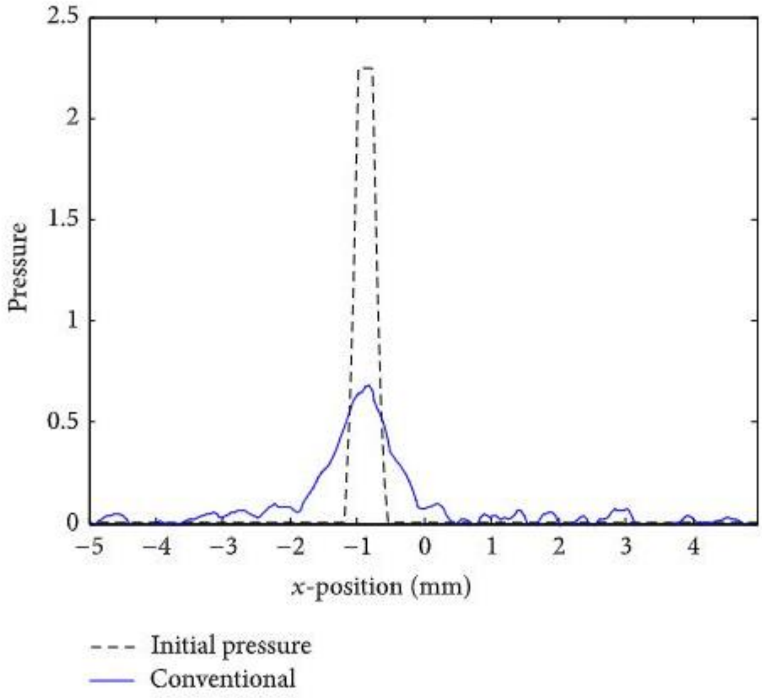


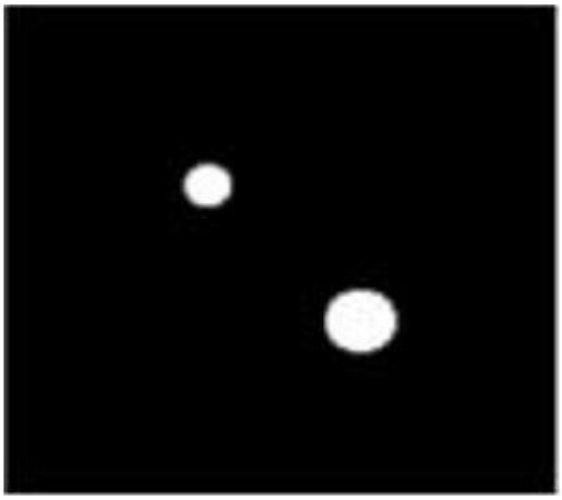
Fig. 3. Distribution of pressure in initial stage and reversal of time of conventional reconstruction.

4.2 Time Reversal Reconstruction Build on Interpolation Method of PSO-SVM

For real-time applications this algorithm is little slow. Recently there is development of fast PSO optimized SVM interpolation algorithm[10]. Implementation of Real-time algorithm employ these algorithms. In imaging of time reversal of PAT, there is an function of interpolation which is sometimes employed to structure missed out pixel values of Cartesian raster. There are some commonly-known algorithms of interpolation to reconstruct the PAT images , they are such as linear interpolation, interpolation of cubic convolution, and interpolation algorithm of cubic spline .There has been illustration of a two-dimensional photoacoustic image simulation experiment in PAT image reconstruction which gives the effect of the performance of imaging by using interpolation of various categories based on time reversal algorithms to prove the impact and hierarchy of the proposed method. Therefore, the distribution of initial pressure, the heterogeneity of sound, and the surface of measurement will pick up the geometrical shape where K-Wave Matlab toolbox simulates the generation process of the photoacoustic signal .In Figure 4(a) there is representation of image of ideal absorber of sound light, in Figure 4(b) there is representation of c time reversal reconstruction of conventional algorithm reconstruction image, and in Figure 4(c) there is reconstructed image by using algorithm of reconstruction of reversal of time built on Interpolation of SVM optimized in PSO algorithm. Between each measurement point the collected photoacoustic data imperfection is not enough, and there is generation of pseudowave in the reconstruction process when less measurement points are used. So following this there has been demonstration that to in detailed regions using SVM interpolation which is optimized by PSO which is capable to preserve more data of edges and pick-out more artifacts which is also called blurring than the other methods.

Proceedings DOI: 10.21467/proceedings.114

Series: AIJR Proceedings
ISBN: 978-81-947843-8-8
ISSN: 2582-3922



.Fig.4(a) ideal absorber of sound light

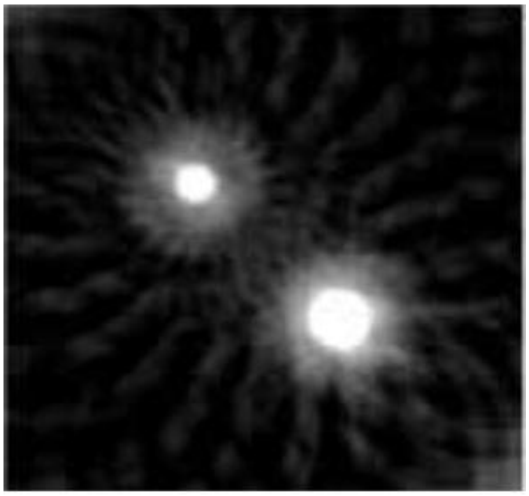


Fig.4(b) c time reversal reconstruction

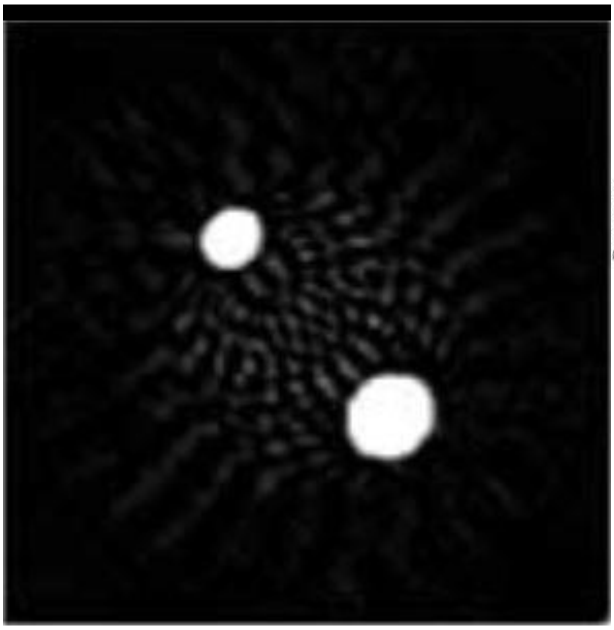


Fig.4(c) Interpolation of SVM optimization

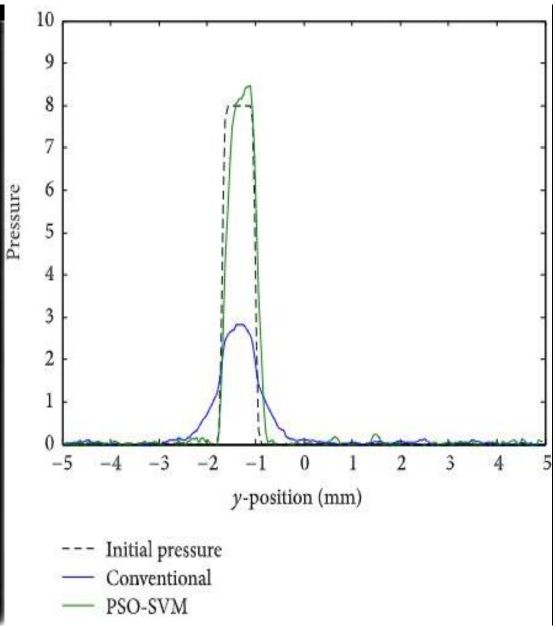


Fig.5. Pressure Distribution Reconstructed

Figure 6(a) shows a phantom of tissue is constructed. The laser radiates the phantom and its is observed that algorithm of filter back-projection(FBP), time reversal algorithm of conventional, and SVM optimized by PSO algorithm of time reversal reconstructes the images of photoacoustic. Results depicted in Figures 6(b)–6(c) indicates that PSO optimized SVM time reversal algorithm reconstructes the image of photoacoustic which depicts the best production, which can gain more initial image particular features than algorithm of reversal of time of conventional and has less amount of artifact objects than algorithm of FBP, and it makes more compatible algorithm for PAT.

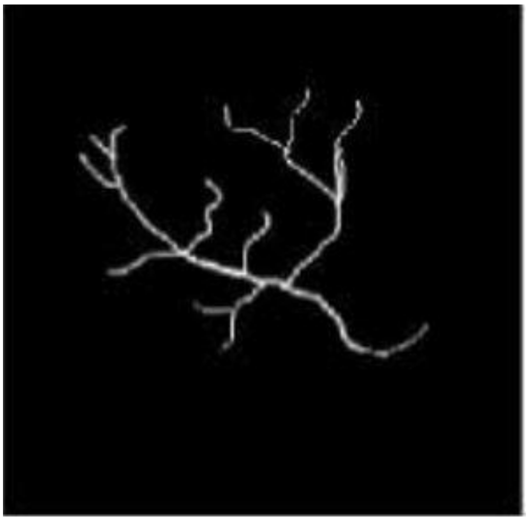


Fig. 6(a) Phantom of tissue is constructed

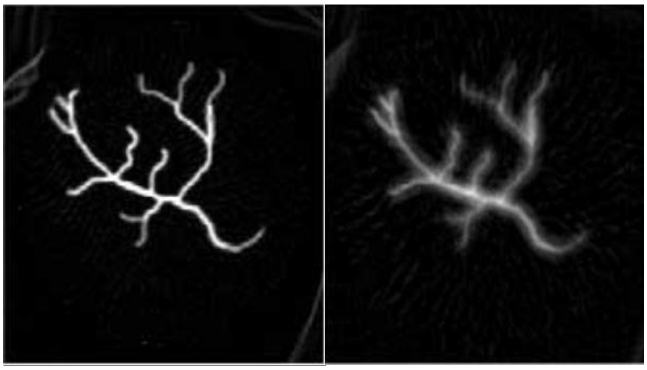


Fig.6(b) Reconstructed image Fig. 6(c) PSO optimized SVM

5 Discussions

In practical sense of imaging of photoacoustic, the surface of measurement is often incomplete or irregular. The acoustic pressure is fixed by the time reversal algorithm at these points which are incomplete make them act as scatters of optic point and may back it scatters into the region of imaging when a discrete measured surface is used. This results in arc-like artifacts across the image. For completion of measurement of surface, which enacts as the boundary in course of reverse of time , there is one way to diminish the artifacts where we can interpolate the data which is measured. The time reversal reconstruction algorithm uses the PSO optimized SVM interpolation method. This method has higher optimization precision and higher convergence rate. There can be effective elimination of the phenomenon of contour jaggies and blurring by the application of optimized method in the course of interpolation. The method is more likely to keep original image details and remove the artifact appearance with better selection of parameter, course of training and many measured procedures. Both the image magnitude and resolution are improved ,so after time reversal reconstruction the effects of acoustic absorption the proposed method can accurately compensate in incomplete imaging of photoacoustic.

6 Conclusions

The basic contribution of the paper is to produce more accurate reconstructed PAT images by the application of algorithm of time reversal built on SVM interpolation optimized by PSO. At the expense of computational speed the revised method will reduce the blurring in the PAT image and background interpolation artifacts. For correcting the attention effect the algorithm is capable. The simulation verifies

Proceedings DOI: 10.21467/proceedings.114

Series: AIJR Proceedings
ISBN: 978-81-947843-8-8
ISSN: 2582-3922

the algorithm effectiveness. Also the SVM interpolation optimized by PSO based algorithm of reversal of time can be used for application in imaging system of PAT of medical services to gain images of resolution of higher range.

References

[1] M.H. Xu and L. V. Wang, "Photoacoustic imaging in biomedicine," *Review of Scientific Instruments*, vol. 77, no. 4, pp. 041101-1-22, 2006.

[2] L.V. Wang, "Prospects of photoacoustic tomography," *Medical Physics*, vol.35, vol.35, no.12, pp. 5758–5767, 2008.

[3] M. H. Xu and L. V. Wang, "Universal back-projection algorithm for photoacoustic computed tomography," *Physical Review E*, vol. 71, no. 1, Article ID 016706, p-7, 2005.

[4] Y. Hristova, P. Kuchment, and L. Nguyen, "Reconstruction and time reversal in thermoacoustic tomography in acoustically homogeneous and inhomogeneous media," *Inverse Problems*, vol. 24, no. 5, Article ID 055006, 2008.

[5] Y. Hristova, "Time reversal in thermoacoustic tomography—an error estimate," *Inverse Problems*, vol. 25, no. 5, Article ID 055008, 2009.

[6] B. E. Treeby and B. T. Cox, "k-Wave: MATLAB toolbox for the simulation and reconstruction of photoacoustic wave fields," *Journal of Biomedical Optics*, vol. 15, no. 2, Article ID 021314, 2010.

[7] B. T. Cox and B. E. Treeby, "Artifact trapping during time reversal photoacoustic imaging for acoustically heterogeneous media," *IEEE Transactions on Medical Imaging*, vol. 29, no. 2, pp. 387–396, 2010.

[8] M. Liyong, S. Yi, and M. Jiachen, "Local spatial properties based image interpolation scheme using SVMs," *Journal of Systems Engineering and Electronics*, vol. 19, no. 3, pp. 618–623, 2008.

[9] T.-C. Ho and B. Zeng, "Super-resolution images by support vector regression on edge pixels," in *Proceedings of the IEEE International Symposium on Intelligent Signal Processing and Communications Systems (ISPACS '07)*, China, pp. 674–677, December 2007.

[10] C. Li, Y. Liu, A. Zhou, L. Kang, and H. Wang, "A fast particle swarm optimization algorithm with cauchy mutation and natural selection strategy," in *Advances in Computation and Intelligence, Lecture Notes in Computer Science*, vol 4683, pp.334-343, 2007.