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Enhancing Mesh-based Photoacoustic Tomography with Parallel Computing on Multiprocessor Scheme

Yao Sun[1,2,*], Zhen Yuan[1,3] and Huaibei Jiang[1]

[1] *Department of Biomedical Engineering, University of Florida, Gainesville, FL 32611, USA.*
[2] *Present Address: Department of Radiology, Wake Forest University Baptist Medical Center, Winston Salem, NC 27157, USA.*
[3] *Present Address: Faculty of Health Sciences, University of Macau, Avenida da Universidade, Taipa, Macau, China.*

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Abstract. Photoacoustic tomography is an emerging technique in biomedicine that is capable of visualizing high resolution structural and functional information of tissue up to several centimeters deep. Mesh based numerical reconstruction algorithms have an unrivaled advantage over other reconstruction algorithms in photoacoustic imaging, due to its accurate mathematical modeling and the capability to recover multiple optical/acoustic parameters in the reconstruction. However the slow reconstruction speed and huge memory cost hindered this advanced reconstruction algorithm from application areas where large scale reconstruction or real/near-real time reconstruction is required, for example, sub-millimeter or micrometer resolution imaging, photoacoustic guided cancer treatment, etc. In this study, we reported a high performance photoacoustic tomography method based on parallel computing strategy with multiprocessor scheme. Our simulation result has shown that the parallelized photoacoustic tomography method using multiprocessor scheme is capable of providing fine reconstructed images of blood vessel structures up to 0.14mm in diameter. Further phantom experiment demonstrated that cross hairs can be clearly reconstructed, when a mesh comprised of 28512 triangle finite elements is used. Therefore, our multiprocessor based parallelized photoacoustic tomography might be promising for large scale reconstruction or real/near-real time reconstruction in biomedical application of mesh-based photoacoustic tomography algorithm.

AMS subject classifications: 35Q, 68U, 68W

Key words: Photoacoustic tomography, finite element method, parallel computing.

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*Corresponding author. *Email addresses:* `yasun@wakehealth.edu` (Y. Sun), `zhenyuan@umac.mo` (Z. Yuan), `hjiang@bme.ufl.edu` (H. Jiang)

1 Introduction

There is a rapidly growing interest in biomedical photoacoustic tomography (PAT), largely because of its unique capability of combining rich optical contrast and high ultrasound resolution in a single modality [1–5]. In biomedical PAT, tissues are illuminated by nanosecond laser pulses and the transient thermoelastic effect in the illuminated tissue leads to the generation of wideband ultrasound pulses, which can be detected by typical ultrasonic transducers and post-processed to form a photoacoustic image with a reconstruction model. Depending on the experimental design and reconstruction model for a specific application, not only anatomical structure but also physiological and functional information of the tissue can be visualized in high resolution to identify and quantitatively evaluate disease and neuron activity in a variety of tissues, such as breast cancer, vascular and skin diseases, epilepsy detection, osteoarthritis imaging, etc. [6–15].

Thus far, several algorithms have been implemented to effectively reconstruct photoacoustic images from measured ultrasonic waves [16–20]. Compared to other methods relying on analytical solutions to the photoacoustic wave equation, finite element (FE) based algorithm is an iterative numerical method that can accommodate tissue heterogeneity and geometric irregularity and has an unrivaled advantage to quantitatively recover multiple parameters [4, 21, 22]. However, both memory-consuming and time-consuming grow dramatically for FE based reconstruction algorithm as scale of the reconstruction increases, which can go beyond the computation limitation of a single PC or computational server even though a graphics-processing-units (GPU) card can be used for the reconstruction acceleration [23–26]. The huge computational burden of finite element based reconstruction algorithm has hindered this powerful reconstruction algorithm from application areas where large scale reconstruction or real/near-real time reconstruction is required, for example, sub-millimeter or micrometer resolution imaging, 3D reconstruction, photoacoustic guided cancer treatment, etc. Currently multiprocessor personal computer and workstation becomes prevalent in the market, and distributed computing or cluster computing like those used in cloud computing is readily available for public users with very low price. By spreading the entire computational cost to multiprocessors with shared or distributed memories, parallel computing strategy could enhance the reconstruction algorithm of FE-PAT by a factor around the number of processors used. This parallel computing strategy has been used in our previous studies for three dimensional photoacoustic imaging of finger joints and osteoarthritis detection [12–14], however no algorithm has been reported yet. Here in this paper, we reported the detail algorithm of the multiprocessor based parallelized FE-PAT method in frequency domain, and the reconstruction examples have been followed to validate the algorithm.

2 Finite element based PAT algorithm

For finite element based photoacoustic tomography (FE-PAT), the reconstruction algorithm in frequency domain is based on the following photoacoustic equation [4] dis-