A Diffraction Tomography Method for Medical Imaging Implemented on High Performance Computing Environment

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Abstract. The efficient implementation of a diffraction tomography method for medical imaging is addressed within the framework of High Performance Computing (HPC) environment. A non-linear optimization method for the solution of the inverse scattering problem is implemented on a shared memory model computer. Linear speed-up and significant reduction in the total execution time is achieved when the program is executed in parallel, enabling the feasibility of the method for realistic medical imaging applications.

1 Introduction

Diffraction tomography is a multiview imaging procedure where cross-sections of an object are reconstructed from scattered field measurements. The object is usually illuminated from many incident directions by a diffracting energy source, such as ultrasound or microwaves. Contrary to Computed Tomography (CT) where the laws of geometric optics are applied, in diffraction tomography the interaction between the incident field and the scattering object can only be described accurately in terms of the wave equation. Methodologies and techniques developed for the solution of the inverse scattering problem are applied in diffraction tomography. Inverse scattering is defined as the problem of finding the shape and refractive index of an inhomogeneous object from scattered field measurements performed on the object's exterior. The development of a diffraction tomography method for medical imaging is highly desirable, since it is based on the use of non-ionizing ultrasonic or electromagnetic radiation, which is considered safe at relatively low exposure levels.

Early attempts in inverse scattering relied on the linearization of the problem using the first order Born or Rytov approximation [1,2]. Despite their mathematical simplicity, these methods are useful only when the size of the scattering object is comparable to the wavelength of the incident wave and its index of refraction is not significantly different from that of the surrounding medium [3]. In order to overcome the stringent limitations of the first order, linear methods, non-linear inverse scattering methods have also been investigated [4-6]. Lately, non-perturbative methods for inverse scattering solution have been proposed, based on non-linear optimization techniques [7-9]. These methods have no theoretical restriction regarding the size or refractive index of the scattering object. However, the necessary discretization of the scattering integral equations, usually leads to an increased number of unknowns for any problem of practical importance.

Inverse scattering is a typical time consuming problem and the response time of its execution is obviously critical. A HPC architecture is an ideal platform for implementing applications that exhibit the above characteristics. Although a variety of inverse scattering methods have been reported in the literature, as far as we know none of them has addressed the problem of practical implementation of an inverse scattering method on a HPC environment.

The purpose of this work is to demonstrate the parallel execution of an inverse scattering algorithm on a HPC platform leading to the development of a realistic diffraction tomography technique for medical imaging. According to the proposed scenario, a number of different clinical sites will be connected with a HPC center where the inverse scattering algorithm will be executed. In section 2, a brief theoretical background of the proposed inverse scattering method is presented. The parallel implementation of the proposed inverse scattering algorithm on HPC architectures is discussed in section 3 along with the evaluation results. The description of the interconnection scheme between the HPC center and the clinical sites is given in section 4. Summarizing concluding remarks and a brief discussion for future work are given in the final section of this paper.

2 Theoretical Background

Any practical implementation of a diffraction tomography technique requires an efficient and accurate solution of the inverse scattering problem. A non-perturbative method for inverse scattering solution, based on non-linear optimization and plane wave expansion of the field inside the scatterer, has been proposed recently [10] and is briefly presented in this paragraph.

For the sake of simplicity, only two-dimensional (2D) problems will be considered. In practice, most realistic imaging problems are three-dimensional (3D) since the properties of biological bodies vary in all three spatial directions. However, if reasonable focusing of the incident wavefield can be achieved along the axis perpendicular to the plane of propagation, the contribution of out-of-plane scattering effects can be neglected without introducing significant error. Since the term "tomography" refers to a 2D imaging procedure, the 3D structure of the object under investigation can be reconstructed from a series of successive 2D cross-sectional images. A time dependence $\exp(-i\omega t)$ where ω is the angular frequency, is assumed and omitted throughout. Furthermore, we assume that the wave propagation is described by the scalar Helmholtz equation.

We consider the situation depicted in Fig. 1 where a plane monochromatic wave $\psi_0(\mathbf{r}) = \exp(ik_0\hat{\mathbf{s}}_j \cdot \mathbf{r})$ is incident on a dielectric object characterized by the complex refractive index $n_r(\mathbf{r})$. The object is embedded in a uniform background with refractive index n_0. The wavenumber $k(\mathbf{r})$ is related with the refractive index

$$k(\mathbf{r}) = k_0 n_r(\mathbf{r}) \tag{1}$$