ADAPTIVE FINITE ELEMENT METHODS FOR FLUORESCENCE DIFFUSE OPTICAL TOMOGRAPHY

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ABSTRACT

Fluorescence Diffuse Optical Tomography (FDOT) is an emerging molecular imaging modality with applications in small animal and deep tissue imaging. FDOT uses visible or near infrared light to reconstruct the concentration and pharmacokinetics, as well as the life time of fluorophores injected into the tissue, based on a mathematical model of light propagation in turbid media. Due to the diffusive nature of light propagation in tissue, FDOT image reconstruction is a highly nonlinear, inherently three-dimensional, and computationally intense inverse problem. This thesis focuses on developing discretization error analysis and subsequent spatially varying resolution techniques to address the tradeoff between the reconstruction accuracy and the computational requirements of FDOT.

In the first part of the thesis, we formulate the FDOT inverse problem as an optimization problem with Tikhonov regularization under the assumption of noise-free measurements. We next analyze the effect of forward and inverse problem discretizations on the accuracy of FDOT reconstruction. Our analysis identifies several factors that determine the extent to which the discretization affects the accuracy of reconstructed fluorescence optical images. Based on our error analysis, we develop adaptive mesh generation algorithms with the objective of increasing the reconstruction accuracy while keeping the discretized forward and inverse problem sizes within allowable limits. In the simulation study, we demonstrate the effectiveness of our new algorithms and compare it with those of the uniform and conventional adaptive meshing schemes.

In the second part of the thesis, we consider measurements corrupted by additive noise and formulate the FDOT inverse problem as an optimization problem in the maximum *a posteriori* framework. We analyze the effect of measurement noise in the FDOT forward and inverse problem discretizations and develop adaptive mesh generation alogrithms that take into account noise statistics as well as *a priori* information on the fluorophore concentration. In the simulation study, we evaluate the performance of our new adaptive mesh generation algorithms and compare

their performance with those of the uniform meshing scheme and the algorithms developed in the first part of the thesis.

We apply our new adaptive mesh generation algorithms to FDOT reconstruction using data from a phantom experiment, and demonstrate the practical advantages of our algorithms in real FDOT reconstruction.

Finally, we note that while our focus has been the FDOT inverse problem, the methods and algorithms developed in this thesis can be adapted to other partial differential equation based inverse parameter estimation problems, such as diffuse optical tomography, bioluminescence tomography, electrical impedance tomography, and microwave tomography.