IDENTIFYING AND ADDRESSING THE ERROR SOURCES IN DIFFUSE OPTICAL TOMOGRAPHY

By

Murat Güven

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Examining Committee:

Birsen Yazıcı, Thesis Adviser
Eldar Giladi, Member
Badrinath Roysam, Member
Qiang Ji, Member
Xavier Intes, Member

Rensselaer Polytechnic Institute
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ABSTRACT

Diffuse Optical Tomography (DOT) is a minimally invasive imaging modality that makes use of the light in the Near-Infrared (NIR) spectrum. The inverse problem in DOT involves reconstruction of spatially varying absorption and diffusion coefficients as well as fluorophore lifetime and yield in tissues from boundary measurements. These fundamental quantities can be utilized to obtain tissue oxy- and deoxyhemoglobin concentrations, blood oxygen saturation, water and fat amount, and to observe uptake and release of contrast agents and organelle concentration in tissue. The unique physiological and biochemical information offered by DOT is very valuable for practical applications such as breast cancer diagnosis, cognitive activity monitoring, brain tumor and hemorrhage detection, functional muscle imaging with a growing list of applications in molecular and cellular imaging.

Diffuse Optical Tomography (DOT) poses a nonlinear ill-posed inverse problem. Furthermore, propagation of NIR light is not restricted to a plane owing to the diffuse nature of photons in turbid media. As a result, DOT is an inherent 3D problem and suffers from low spatial resolution. One has to address all of these drawbacks in order to provide accurate and computationally viable optical image reconstructions.

This thesis focuses on the factors that affect the accuracy of DOT imaging and on how to eliminate these factors. In this context, we present an error analysis to show the effect of the discretization of the forward and inverse problems, and the linearization of the inverse problem on the accuracy of the reconstructed optical images.

First, we consider the inverse problem for which we reconstruct the unknown optical absorption coefficient of a bounded optical medium while the optical diffusion coefficient is assumed to be known. Then, we analyze the error in the reconstructed optical absorption images resulting from the discretization of the forward and inverse problems and the linearization of the inverse problem by Born approximation. Our analysis identifies several factors which influence the extent to which

the discretization and Born approximation impact the accuracy of the reconstructed optical absorption images. For example; the mutual dependence of the forward and inverse problems; the number of sources and detectors, their configuration and their locations with respect to optical heterogeneities. Based on the error analysis, we propose novel adaptive discretization schemes for the forward and inverse problems. The proposed discretization schemes lead to adaptively refined composite meshes that yield the desired level of imaging accuracy while reducing the size of the discretized forward and inverse problems.

Finally, we extend our error analysis for the simultaneous reconstruction of the unknown optical absorption and diffusion coefficients. For this problem, while the model for NIR light propagation remains the same, the inverse problem formulation becomes more challenging since two parameters need to be estimated simultaneously. Our analysis shows that the error in the reconstructed optical images due to forward problem discretization depends on the solutions of the inverse problem. Similarly, the error due to inverse problem discretization depends on the solutions of the forward problem, thereby implying the inter-dependence of the forward and inverse problems. One important implication of the analysis is that poor discretization of one optical parameter may lead to error in the reconstruction of the other. Based on the error analysis, we develop adaptive mesh design algorithms which are of low computational complexity as compared to the computational complexity of solving the respective problems, namely the discrete forward and inverse problems.