A Generalized Least-squares minimization method for near infrared diffuse optical tomography

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Diffuse optical tomography (DOT) has the potential to become a non-invasive and non-ionizing diagnostic imaging technique for breast cancer imaging. DOT uses near-infrared (NIR) light to illuminate the breast, generally through the use of fiber optic bundles, and the diffusely transmitted light is collected from the tissue surface. To get functional images of the breast, one needs to use advanced model-based reconstruction methods with these measurements. Accurate modeling of the scatter-dominated transport process leads to a non-linear transport model, which is difficult to solve. A thorough understanding of existing methods and the development of improved novel computational approaches are vital in the process of making diffuse optical imaging a viable clinical tool.

The critical computational parameters were analyzed, such as the finite element mesh resolution and number of boundary measurement points, for their effect upon the reconstructed image quality. The results indicated that increasing number of measurements tends to make the sensitivity of the domain more uniform and reduces the hypersensitivity near the boundary.

A simple framework to incorporate structural priors into the optical image reconstruction procedure is presented through the use of simple weight matrices. This approach can be used in hybrid-optical imaging (e.g. MRI-coupled with NIR), and was proven to be less sensitive to slight imperfections, commonly caused by segmentation or tissue identification or mesh resolution issues, in the given spatial-prior information.

In this thesis, an improved optical image reconstruction method is developed, which takes into account the possible errors associated with the collection of data. This formalized frame-work uses the generalized least-squares (GLS) approach, where the aim is to match the experimental data with the modeled data, using a least-squares minimization, with inclusion of a regularization term to stabilize this ill-posed problem.

This thesis also developed a computationally efficient approach to dramatically reduce the size of the matrix to be inverted in cases where the number of imaging parameters are much larger than the boundary data available. This algorithm reformulates the inversion approach, within most least-squares approaches, to allow the inversion to be based upon the size of the data, rather than the number of imaging field parameters, and this is useful for most three-dimensional (3D) imaging situations.

Prior spatial and spectral information about the tissue is used to improve the spatial resolution and stability of the reconstruction procedure. This GLS approach was able to give reasonable estimates of spectrally-derived tissue functional properties even in cases of highly noisy experimental phantom data.