

A multi-modality image reconstruction platform for diffuse optical tomography

Q. Fang[#], S.A. Carp[#], J. Selb[#], R. Moore^{*}, D.B. Kopans^{*}, E.L. Miller[†], D.H. Brooks[‡], and D.A. Boas[#]

[#]Massachusetts General Hospital, Athinoula A. Martinos Center for Biomedical Imaging, Charlestown, MA 02129

^{*}Massachusetts General Hospital, Department of Radiology, Boston, MA 02114

[†]Tufts University, Boston, MA 02155

[‡]Northeastern University, Boston, MA 02115

fangq@nmr.mgh.harvard.edu

Abstract: We present a software platform for image reconstruction and data analysis for diffuse optical tomography. The structure, algorithm and functionalities of the platform are reported together with the sample results produced by the platform.

©2007 Optical Society of America

OCIS codes: 170.1470, 170.2655, 170.3660, 170.3880, 170.6280, 170.6930, 170.6935

1. Introduction

Fusing functional with anatomical information to create multi-modality images becomes increasingly popular in developing novel imaging methods for cancer diagnosis [1]. This allows researchers to take advantage of the novel biomarkers revealed in the functional imaging modality while retaining the high resolution structural information from the traditional imaging methods. Diffuse optical tomography (DOT) is a promising functional imaging method that targets at angiogenic and metabolic properties of the tissue [2, 3] and was increasingly used in conjunction with anatomical imaging modalities such as CT, X-ray [4] and MRI [5]. The data fusion process of the DOT with structural images requires more sophisticated software tools to interface, register and synergistically process the data from multiple sources. At Massachusetts General Hospital (MGH), we have been developing a combined DOT with 3D X-ray mammography (tomosynthesis) for breast imaging in the past few years [4, 6]. In parallel to building the imaging instrument, we have also developed an image reconstruction and data analysis software platform. This software package includes various programs to perform the tasks for data preprocessing, image reconstruction and post-processing. In this report, we present the general structure of the software, functionality of each individual unit, summary of algorithms and the data processing examples.

2. Materials and Methods

Work Flow and Software Structure. The work flow for analyzing the combined DOT/tomosynthesis data is shown in Fig. 1. Our imaging system can produce spatially co-registered optical and X-ray measurements for the target breast. The multiple X-ray projections are combined into a 3D image with slice thickness of 0.1 mm in x and y directions and 1 mm in z direction. The produced 3D X-ray image is subsequently mapped to optical probe coordinates by manually specifying the coordinates of the landmarks. The optical source and detector fiber positions are mapped and plot on top of the registered X-ray images. Not all of the sources/detectors are covered by the breast in most experiments; the measurements associated with those uncovered source/detectors will be automatically removed based on the registered optode maps. Additionally, the registered X-ray scan can be used to extract the breast surface to model the geometry. After smoothing and re-sampling, the surface mesh can be used to create a volumetric tetrahedral mesh. Alternatively, we implemented a simple mesh generator that produces uniform tetrahedral (T5-type) elements truncated by the spatial extend of the target from the X-ray image [6].

With the calibrated measurements and the breast geometry, we perform optical image reconstruction using the finite element (FE) method [7] as the forward solver and Gauss-Newton method as the estimator for the optical and physiological properties of the breast, namely, oxy-/deoxy-hemoglobin (HbO/HbR), water and lipid concentrations, optical absorption (μ_a) and scattering coefficients (μ_s'). This is achieved in 3 steps: 1) we first estimate the bulk optical properties of the target breast by treating the whole breast as a uniform material, 2) using the bulk properties as a homogeneous initial guess, we perform a full image reconstruction to recover the 3D distributions of the breast physiological properties, and 3) using the X-ray image segmentations as a spatial prior, we estimate the physiological properties for different types of tissues, i.e. muscle, fibroglandular, fatty tissues and lesions.

For each processing step in Fig. 1, we wrote software to perform the task and automate the processing. This creates a set of tools for multi-modal data analysis, particularly for diffusion optical tomography with structural information. These tools include preprocessing software "Tobinator" and image reconstruction platform "Redbird2".

Algorithm Overview. Redbird2Core is a FORTRAN90-based DOT image reconstruction program. In this program, we used an FE solver to model the light diffusion process in the tissue. A multi-right-hand-side iterative solver as used to solve the linearized diffusion equation over the FE mesh [8]. Redbird2Core also include a flexible

image reconstruction module. Users can choose to either use single wavelength measurement for reconstructing optical properties at the given wavelength, or do a multi-spectral reconstruction to simultaneously use the optical measurement from multiple wavelengths[9, 10]. Unified geometry and source/detector representation have been developed to allow users to model a variety of target and source/detector distributions (for example, cylindrical or parallel source array). The image reconstruction also provides switches to enable log-amplitude phase form object function and simultaneous source/detector calibration [6].

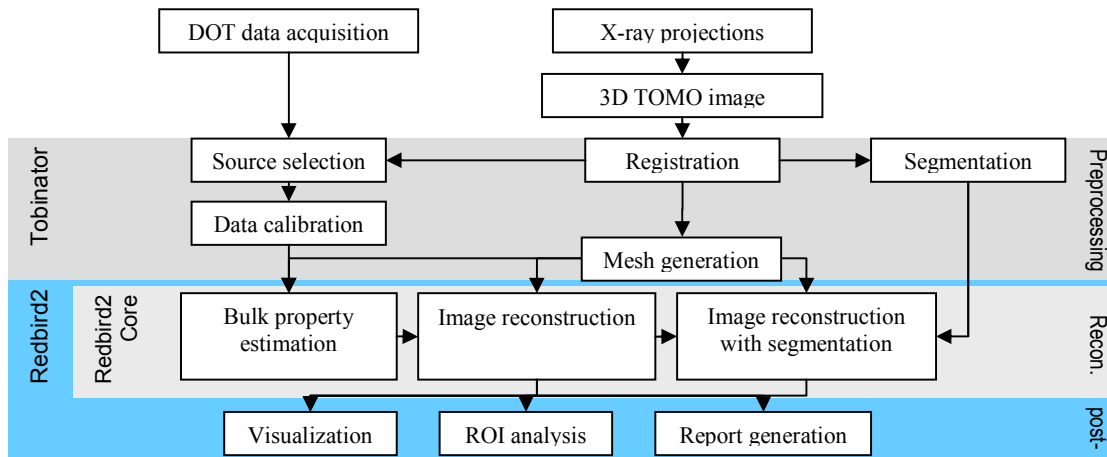


Figure 1. Data analysis work flow and software modules to perform the tasks.

Scripting and Automation. The software package Redbird2 includes a scripting system written in perl. The included scripts provide the following functionalities: 1) create and maintain a hierarchical structure of the input/output for each measurement data set and reconstruction session, 2) call the data pre/post processing scripts and image reconstructor to perform image reconstruction tasks, 3) allow users to run tasks in interactive mode or streamlined command mode, provide task-level parallelization when running on clusters or parallel architectures, 4) provide programming interfaces to allow users access to sophisticated tasks to explore reconstruction parameters and various algorithms using perl syntax. The last function of the scripting system is particularly important for research purposes where one can fine tune a variety of parameters to pursuit optimal solutions.

Interfaces and Extensions. The image reconstruction code and scripting system in Redbird2 provides interfaces to allow users to extend the functionality of the platform to their particular application. In the scripting system. We provide a “plug-in” mechanism that allows users to insert their application-specific variables and subroutines to the program, in addition to the programming interface mentioned above. The Redbird2Core image forward/reconstructor contains various modules, such as dual-mesh, forward solver, inverse solver, user I/O, utilities etc, which provide a clear structure for the user to customize and enrich the functionalities of the software. The source code of Redbird2Core will be available under an open-source license in the near future.

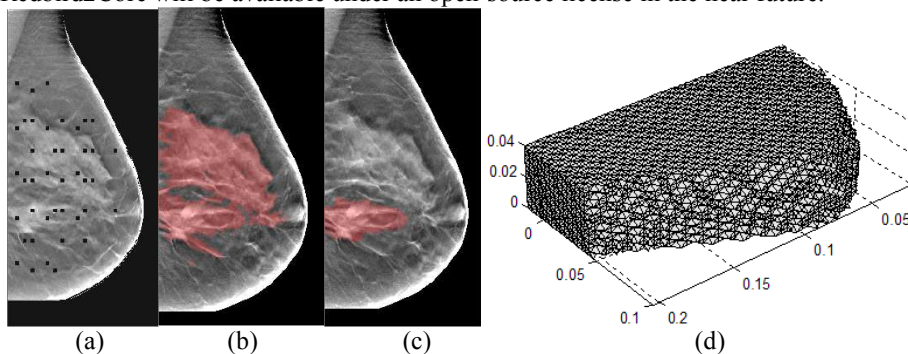


Figure 2. Image outputs in data preprocessing: (a) optical source registration (the black dots denote source positions), (b) segmentations of fibroglandular and tumor regions, (c) tumor segmentation, (d) breast FEM forward mesh

3. Results and Discussion

Data preprocessing. In this section, we show the outputs of each data processing step using the presented software package to demonstrate the key functionalities. The example shown here is the right breast measurements from a 63-year-old woman, who had a 3cm invasive lesion in the breast. The raw image slice of the tomosynthesis image is

shown in Fig. 2 (a) where the source/detector optical fiber positions after registration are shown as black marks. Using free software Insight-SNAP[11], we created the 3D segmentations of the fibroglandular region and the tumor region separately (Fig. 2 b-c). The forward and reconstruction FEM mesh of the breast is shown in Fig. 2 (d).

The bulk optical property estimation from the optical measurement at 685nm and 830nm results in $21.2 \mu\text{M}$ HbO, $5.4 \mu\text{M}$ HbR, $1.9\text{e-}3 \text{ (m}^{(b-1)})$ for scattering amplitude and 0.92 for scattering power. Using these values as initial guess, we reconstructed the total hemoglobin concentration (HbT=HbO+HbR), oxygen saturation (SO_2) and scattering coefficient distributions across the breast. We overlapped the contours of the fibroglandular/tumor segmentations on top of the image and the results are shown in Fig. 3.

From the HbT and scattering coefficient images, we can see a positive contrast of 1.4:1 to the background tissue tightly bounded by the tumor contour. On the corresponding SO_2 image, the tumor region and the fibroglandular region present a lower SO_2 value indicating a higher metabolism. These results are consistent with the literature[5].

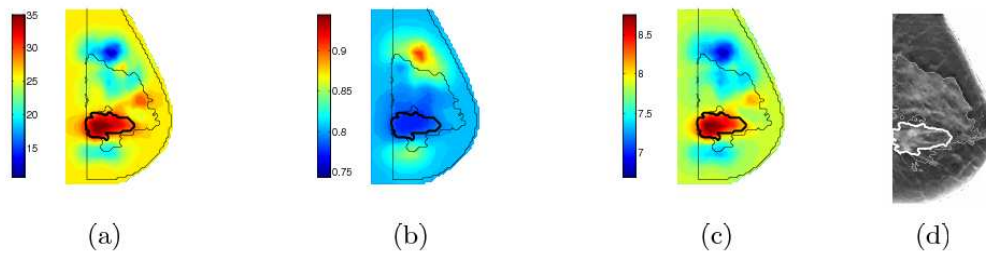


Figure 3 Reconstructed optical images: (a) HbT, (b) SO_2 , (c) μ_s' (830nm), and (d) X-ray with ROI overlays

4. Conclusion

We have described a data analysis work flow and software platform for multi-modality data fusion using diffuse optical tomography and co-registered anatomical structures. The key functionalities and software structure of the platform were outlined and a clinical data processing example was given. The software is self-contained and can be compiled on multiple platforms. The image forward solver and reconstructor have incorporated many up-to-date image reconstruction algorithms in the DOT field and the resulting functional/structural image overlays are quite convenient for image interpretation. The flexible and modularized software interface open the path for researchers to explore the optimal results by fine tuning algorithm parameters. The scripting system also allows batch processing a large body of clinical data efficiently. The source code of the platform will be released under open-source licenses. We believe that with the participation of the researchers worldwide, this software platform will become more versatile and robust.

5. References

1. Gould, P., *The rise and rise of medical imaging: The state of the art in medical imaging technology*. Physics World, 2003.
2. Hebden, J.C., S.R. Arridge, and D.T. Delpy, *Optical imaging in medicine: I. Experimental techniques*. Phys. Med. Biol., 1997. **42**: p. 825-840.
3. Gibson, A.P., J.C. Hebden, and S.R. Arridge, *Recent advances in diffuse optical imaging*. Physics in Medicine and Biology, 2005. **50**: p. R1-R43.
4. Zhang, Q., et al., *Coregistered tomographic x-ray and optical breast imaging: initial results*. J Biomed Opt, 2005. **10**: p. 024033.
5. Brooksby, B., et al., *Imaging breast adipose and fibroglandular tissue molecular signatures by using hybrid MRI-guided near-infrared spectral tomography*. PNAS, 2006. **103**(23): p. 8828-8833.
6. Fang, Q., et al., *Combined optical imaging and mammography of the healthy breast: optical contrast derived from breast structure and compression*. IEEE Trans. Medical Imaging (submitted), 2007.
7. Arridge, S.R., *Optical tomography in medical imaging*. Inv. Problems, 1999. **5**: p. R41-R93.
8. Boyse, W.E. and A.A. Seidl, *A block QMR method for computing multiple simultaneous solutions to complex symmetric systems*. SIAM J. Sci. Comput., 1996. **17**: p. 263-274.
9. Li, A., et al., *Reconstructing chromosome concentration images directly by continuous-wave diffuse optical tomography*. Optics Letters, 2004. **29**(3): p. 256-258.
10. Srinivasan, S., et al., *Near-infrared characterization of breast tumors in vivo using spectrally-constrained reconstruction*. Technology in Cancer Research & Treatment, 2005. **4**(5): p. 513-526.
11. Yoo, T.S., et al., *Engineering and Algorithm Design for an Image Processing API: A Technical Report on ITK - The Insight Toolkit*. In Proc. of Medicine Meets Virtual Reality, 2002: p. 586-592.