Frequency Shifting Model for Diffuse Optical Tomography

Huseyin Ozgur Kazanci (ozgurkazanci@gmail.com)
Akdeniz University Faculty of Engineering https://orcid.org/0000-0003-0036-7657

Research Article

Keywords: Frequency domain (FD) diffuse optic tomography (DOT), frequency shifting.

Posted Date: July 19th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-557771/v1

Abstract

Diffuse Optical Tomography (DOT) imaging technique has been interesting research field for researchers since it has uncertainties in the solution space. DOT modality is unsolved scientific problem. Inverse problem solution and image reconstruction has never been in its best quality. Reconstructed images have low spatial resolution. Scattering nature of diffusive light is the obscuring effect for DOT modality. DOT has 3 functional sub-branches which of these are Continuous Wave (CW), Time-Resolved (TR), and Frequency-Domain (FD). In this work, one new approach to Frequency Domain Diffuse Optical Tomography (FDDOT) biomedical optic imaging modality is presented to the readers. Frequency Shifting data were added to the forward model problem which basically has source-detector couplings and number of imaging voxels. 100 MHz center core light modulation frequency was selected. 169 source-detector matches were used on back-reflected imaging geometry. Absorption coefficient m_a was selected 0.1 cm^{-1}. Scattering coefficient μ_s was selected 100 cm^{-1}. 1 micrometer x, y, z cartesian grid coordinates were used in each direction for imaging tissue-like simulation media. The total of 100 frequency shift was added to the forward model problem which has 5 Hz frequency step. 2 inclusion objects were embedded inside the imaging simulation phantom. 2 inclusion images were successfully reconstructed with the low contrast to noise ratio (CNR) error and position error (PE). Frequency shifting technique is first applied for FDDOT here. This technique has increased the total number of equations in the forward model problem; hence it is helping to solve the inverse problem. In this work, the positive effect of using multi frequency methodology was observed. Differentiation of 2 embedded inclusions was successfully completed and illustrated in this work.

1. Introduction

Diffuse Optical Tomography (DOT) technique is the biomedical optic imaging modality. DOT method has important research opportunity, since its reconstructed image quality has low quality and it needs to be developed. For 3–4 decades, researchers have been working to develop the DOT image quality. DOT devices are running based on the scattering and absorbing nature of light. Low power light scatters inside the heterogeneuous imaging tissue depend on the scattering feature of laser source. Migrating low-power laser light was also absorbed by the heterogenuous tissue biomolecules inside the tissue. Migrating light inside the tissue is building forward model problem which consists of tissue voxels` m_a absorption coefficiensts. The main purpose of the DOT technique is to solve these absorbers. In the inverse problem solution algorithms, these absorption coefficients were calculated and mapped inside the 3-dimensional tissue imaging geometry. Image reconstruction algorithms are solving the inverse problem. DOT modality has 3 functional sub-branches, these are: Continuous Wave (CW), Time-Resolved (TR), and Frequency-Domain (FD) techniques. In this work, FD technique was selected and novel frequency shifting methodology was applied in the forward model problem. FDDOT biomedical optic imaging technique was recently visited by some groups[1–9]. Phase-shift methodology was also recently studied[10]. Phase-shift is similar to the frequency shift method. In the phase shift method, instead of frequency shifting, phase shifting is applied to the forward model problem. Same forward model problem diffusion equation

was used as mentioned in previuous work[10]. Both methods have advantages over CW and TR imaging methods.

2. Method

13 sources and 13 detectors were placed on the back-reflection imaging geometry. 13 sources and 13 detectors are building 169 source-detector couplings in the forward model problem. 100 frequency shift steps were used in the forward model problem, consequently 169×100 = 16900 matches were supplied. 40 x, y, z grid elements were used in each cartesian coordinate system which has total of 64000 voxel grid elements. Forward model has 16900×64000 vector elements. Tissue absorption coefficient m_a=0.1 cm^{-1}, and scattering coefficient m_s=100 cm^{-1}. Cartesian grid sizes are 1 mm in each direction. 13 sources and 13 detectors were placed on the back-reflected imaging geometry as seen in Fig. 1. Blue diamonds are sources and yellow squares are detectors. Forward model problem was built based on the frequency domain diffusion equation which was shown in[10]. Photon fluencies were generated and mapped inside the imaging tissue simulation geometry. 6th source-detector (SD) match 5th frequency shift photon fluencies were demonstrated at top view in Fig. 2.

3. Result

2 inclusions were embedded inside the imaging geometry as seen in Fig. 3.A for depth and in Fig. 3.B for top view. 2 inclusions were reconstructed and demonstrated for depth view in Fig. 3.C and top view in Fig. 3.D. Contrast to Noise Ratio (CNR) error was calculated as % 5.8. Position Error (PE) was calculated as % 12.3. CNR and PE error calculation formulas were demonstrated[10].

4. Discussion

In this work, frequency-shift simulation data was applied to the FDDOT imaging modality. Forward model-problem equation numbers were expanded by adding frequency shifting method, hence it helped to increase the resolution of reconstructed image quality. Frequency shifting method was first applied in here. It helped to differentiate the two embedded inclusions inside the imaging tissue simulation media. Frequency shifting method is important method for future-promising FDDOT devices. This technique has increased the total number of equations in the forward model problem; hence it is helping to solve the inverse problem. In this work, the positive effect of using multi frequency methodology was observed. Differentiation of 2 embedded inclusions was successfully completed and illustrated in this work.

Declarations

Funding, acknowledgments, and disclosures

Funding

This work was not supported by any project or research money.

Acknowledgments

This work was accomplished in the Antalya, TURKEY.

Competing Interest

The author declares he has no competing interests.

Financial competing interests:

• In the past five years the author has not received reimbursements, fees, funding, or salary from any organization that may in any way gain or lose financially from the publication of this manuscript, either now or in the future. The author works as Associate Prof. Dr. & Researcher at university that are not financing this manuscript (including the article-processing charge).

The author has not held any stocks or shares in an organization that may in any way gain or lose financially from the publication of this manuscript, either now or in the future.

• The author does not hold, or he is not currently applying for any patents relating to the content of the manuscript. The author has not received reimbursements, fees, funding, or salary from an organization that holds or has applied for patents relating to the content of the manuscript.

• They do not have any other financial competing interests.

Non-Financial competing interests:

• There are no non-financial competing interests (political, personal, religious, ideological, academic, intellectual, commercial or any other) to declare in relation to this manuscript.

References

1. Doulgerakis, M., Eggebrecht, A.T., Dehghani, H.: High-density functional diffuse optical tomography based on frequency-domain measurements improves image quality and spatial resolution. Neurophotonics **6**(3), 035007 (2019)
2. Angelo, J.P., Chen, S.-J., Ochoa, M.: “Review of structured light in diffuse optical imaging,” *Journal of Biomedical Optics*, 24(7), 2019
3. Gioux, S., Mazhar, A., Cuccia, D.J.: “Spatial frequency domain imaging in 2019: principles, applications, and perspectives,” *Journal of Biomedical Optics*, 24(7), 2019
4. Hayakawa, C.K., Karrobi, K., Pera, V., et al.: “Optical sampling depth in the spatial frequency domain,” *Journal of Biomedical Optics*, 24(7), 2019

5. Robbins, C.M., Yang, J., Antaki, J.F., et al., “Hand-held multi-wavelength spatial frequency domain imaging for breast cancer imaging,” *Conference on Optical Tomography and Spectroscopy of Tissue XIII*, 2019
6. Doulgerakis, M., Eggebrecht, A., Dehghani, H., “Information rich phase content of frequency domain functional Near Infrared Spectroscopy,” *Conference on Neural Imaging and Sensing*, 2019
7. Sassaroli, A., Tong, Y., Fabbri, F., Frederick, B., Renshaw, P., Fantini, S., “Functional mapping of the human brain with near-infrared spectroscopy in the frequency-domain,” *Proc. SPIE* **5312**, **371**–**377**, 2004
8. Doulgerakis M., Eggebrecht A.T., Culver J., Dehghani H., "Improving Functional Diffuse Optical Tomography Reconstruction Quality Utilizing Frequency Domain Measurements," *Biophotonics Congress: Biomedical Optics Congress (Microscopy/Translational/Brain/OTS), OSA Technical Digest, paper* OF2D.2, 2018.
9. Dehghani, H., Srinivasan, S., Pogue, B.W., Gibson, A., “Numerical modelling and image reconstruction in diffuse optical tomography,” *Philos Trans A Math Phys Eng Sci.*, **367(**1900**)**:**3073**-**93**, 2009
10. Kazanci, H.O.: Photon phase shift imaging research on frequency domain diffuse optic tomography. Opt. Quant. Electron. **53**(258), 1–8 (2021)

Figures

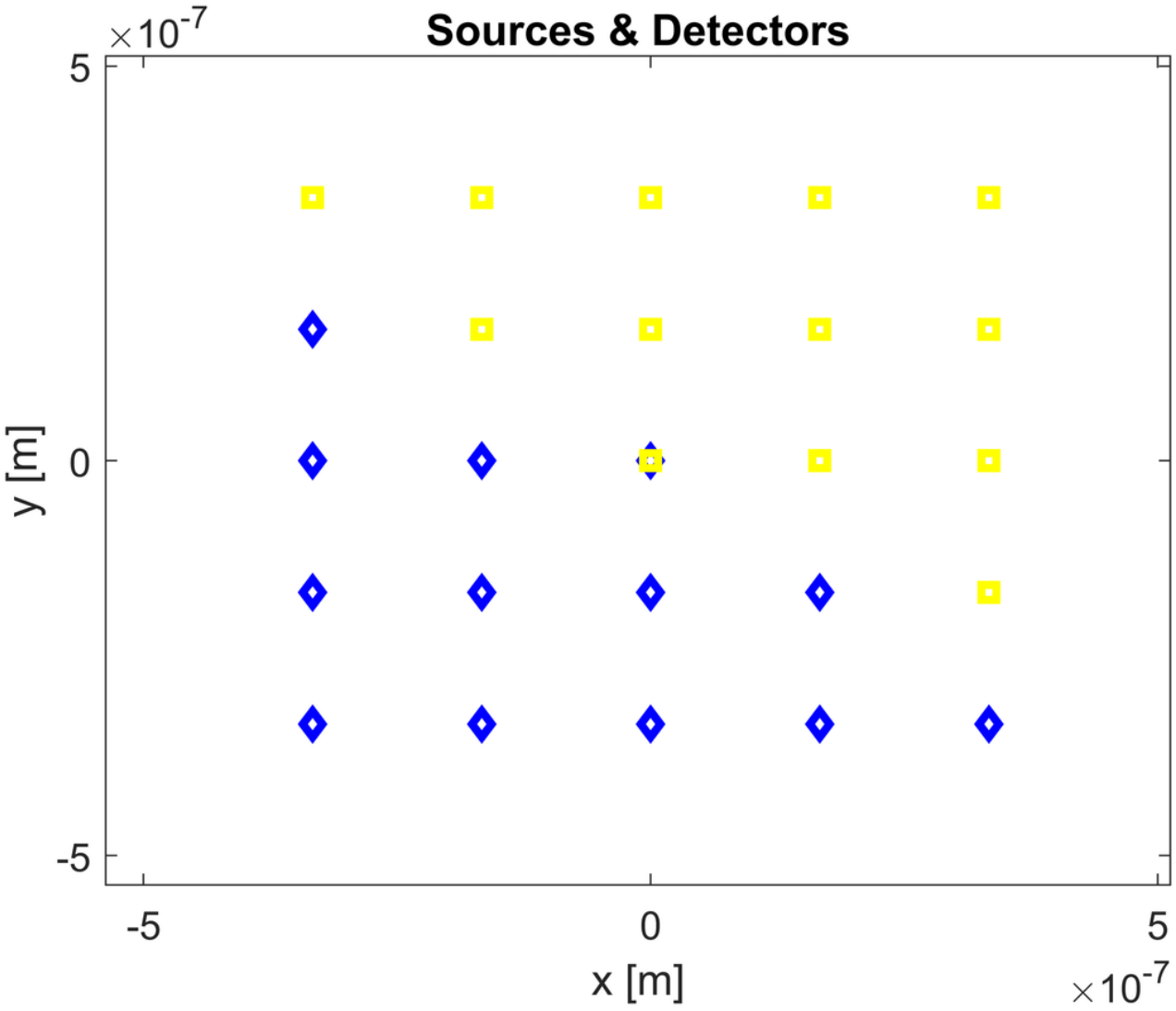

Figure 1

Source and detector placements. Sources are blue, and detectors are yellow.

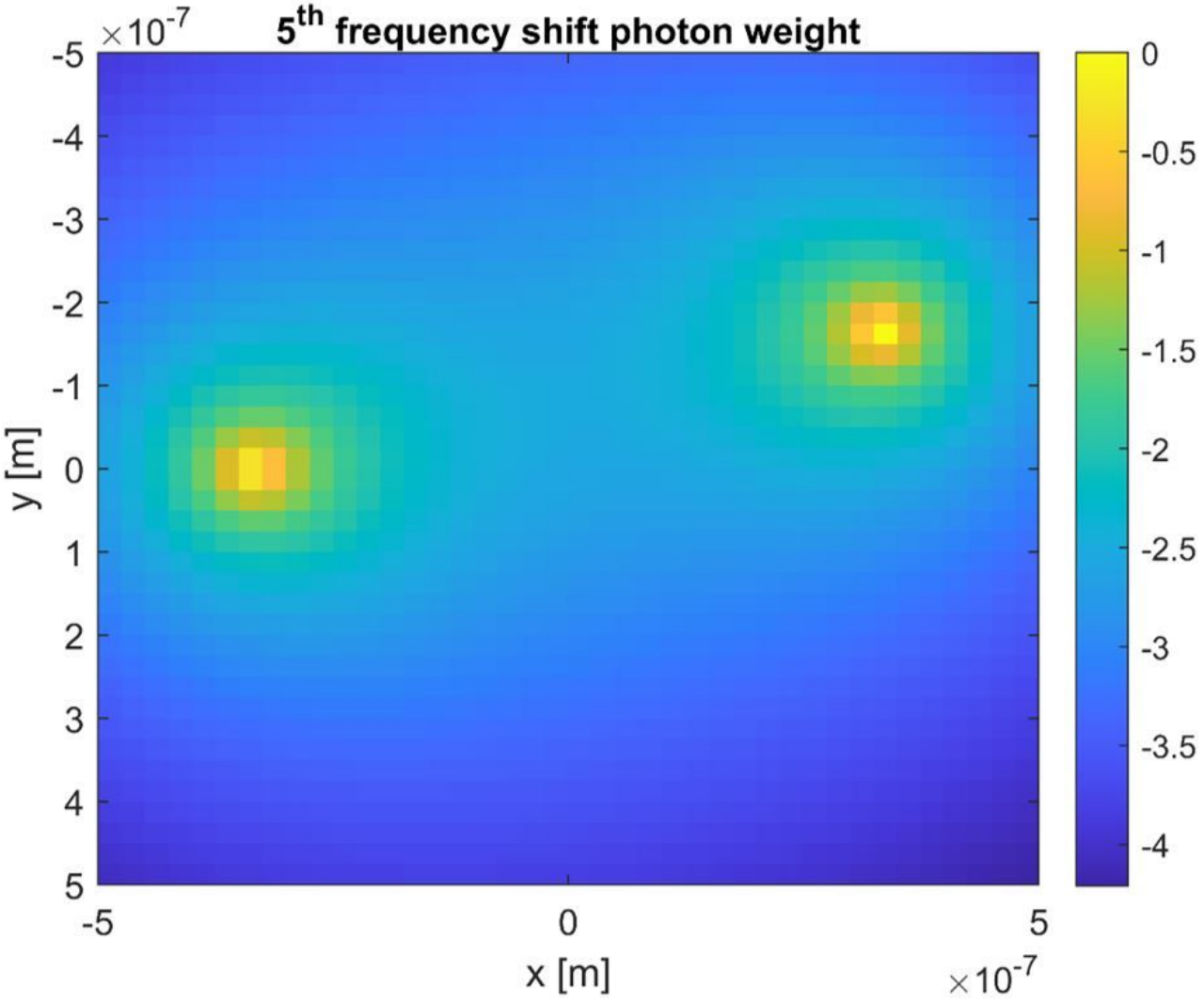

Figure 2

6th source-detector (SD) match 5th frequency shift photon fluencies at top view.

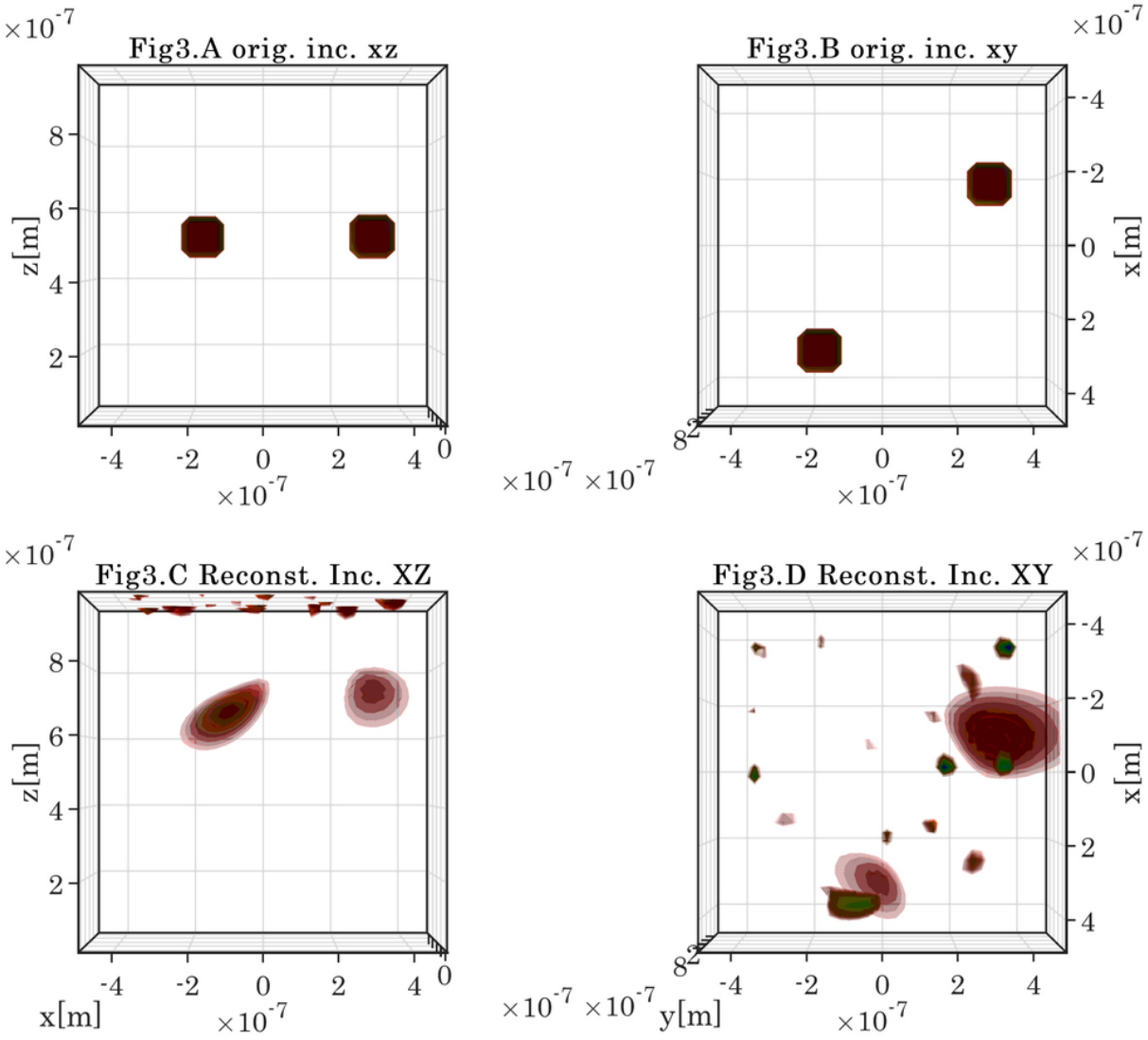

Figure 3

Original and reconstructed inclusion images.