Sagittal-imaging Trans-rectal Optical Tomography Reconstruction with Structural Guidance: Initial Simulative Study

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Abstract: The reconstruction of sagittal trans-rectal optical tomography for prostate imaging is presented with assumption of structural guidance from trans-rectal ultrasound. The spatial prior combined with Jacobian weighing improves the recovery of lesion depth.

OCIS codes: (170.6960) Tomography; (170.3010) Image reconstruction techniques; (170.7230) Urology

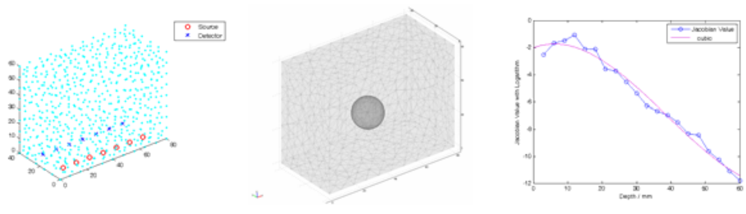
1 Introduction

Recent advancement of trans-rectal optical tomography has been directed toward functional imaging in prostate. Trans-rectal imaging of deep prostate tissue faces significant challenges due to the unique anatomy of prostate as well as the space limitation of placing the trans-rectal applicator. A sagittal imaging NIR probe with optodes arranged in longitudinal dimension is potentially capable of interrogating prostate tissue up to several centimeters. However, accurate localization of lesion in trans-rectal geometry is likely compromised by blind image reconstruction due to the rapid fall-off of NIR sensitivity away from the applicator surface. Integrating spatial information from trans-rectal ultrasound (TRUS) to guide image reconstruction of trans-rectal optical tomography is a tangible solution because TRUS has good resolution for morphologic information and it is the standard office-based imaging modality in urology. Robust integration of spatial ***a priori*** information [1][2] requires that trans-rectal NIR imaging plane coincide with TRUS.

In this paper, the reconstruction of a novel sagittal imaging trans-rectal NIR probe under development is investigated. Simulative studies are presented to demonstrate the improvement of lesion localization with prior spatial information. A Jacobian weighing method is shown to further improve the lesion localization.

2 Forward Simulation

The geometry of sagittal-imaging trans-rectal NIR probe is shown in Fig. 1(a). The probe consists of one source array and one detector array, each with 7 channels. The source/detector channels are placed at 1cm separation, and the source array is placed 2cm from the detector array. The array dimension of 60mm×20mm is designed to couple to a 60mm×10mm commercial TRUS transducer performing sagittal imaging at the middle plane of the NIR array. The minimum source-detector distance of 2cm validates the use of diffusion approximation to radiative transport equation for forward model.



(a) (b) (c)

Fig.1. (a) Imaging geometry; (b), finite-element mesh of the lesion and imaging volume, (c) Jacobian vs. depth

The forward problem is solved by finite-element method in an imaging volume of 80mm × 40mm × 60mm. The finite element mesh of imaging volume is first generated in COMSOL Multiphysics package (see Fig.1 (b)) then embedded to MATLAB-based diffuse optical tomography modeling package NIRFAST. All simulations are conducted with lesions of 10mm in diameter that has background $\mu_a = 0.002mm^{-1}, \mu_s' = 0.8mm^{-1}$ and lesion $\mu_a = 0.025mm^{-1}, \mu_s' = 1.0mm^{-1}$. Simulations are conducted at noise level of 1%. The Jacobian plot in the middle plane of the imaging volume in Fig. 1(c) demonstrates that imaging sensitivity rapidly degrades as the depth increases, indicating the tendency of reconstructing deep lesions in shallower location [3].

3. Image Reconstruction

The lesion depth has been set to 10mm, 20mm, and 30mm in Forward simulation as seen in Fig. 2(a). Blind trans-rectal NIR tomography reconstruction is shown in Fig. 2(b) by use of Newton-type iterative routine in NIRFAST. The lesion is reconstructed closer to the probe surface as expected, and lesion is not identified for depth of 30mm that is ½ of the array dimension.

The hard spatial priori information [4] from TRUS is modeled by the dual mesh method [5] where the suspicious lesion is represented by FEM mesh of higher element density. Reconstructed images are shown in Fig. 2(c). Compared with images reconstructed without the prior, localization of the lesion is improved moderately for all depths. However, significant artifacts appear in particular for deeper targets.

A Jacobian weighing method [5] is implemented in addition to the spatial prior. By dividing the imaging volume to 12 layers of depth, the weight for each layer is determined by: $W_i = \{\max[J(layer_i)]/\max[J(layer_1)]\}^{-1}$, and the Jacobian value of each layer is updated by : $J_{i\_new} = J_{i\_old} \cdot W_i , \quad i \in \boldsymbol{layer_i}$. Images of this approach are shown in Fig. 2(d) with much improved localization accuracy and significantly reduced artifacts.

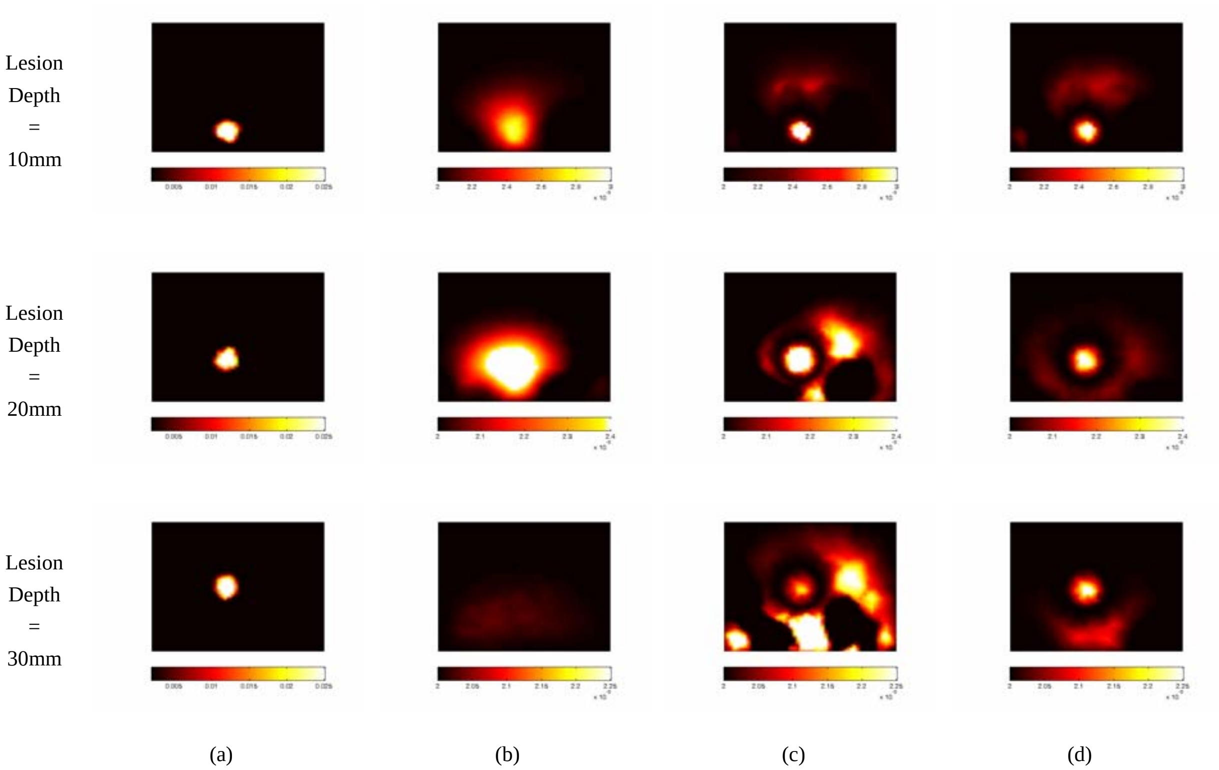


Figure 2 Comparison of target image (a) with blind NIR reconstruction (b), spatial prior (c), and spatial prior + Jacobian weighing (d).

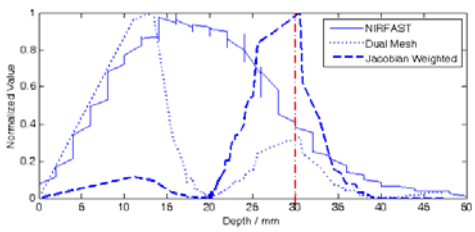
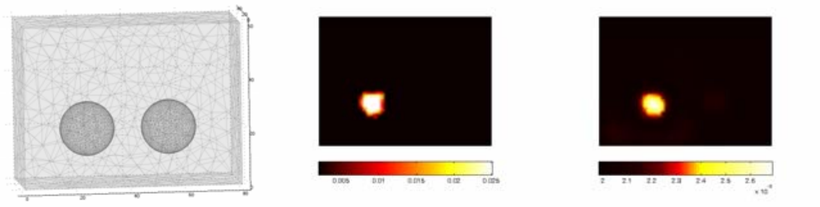


Fig. 3. Comparison of Three Methods

A depth-resolved absorption value along the center of lesion at 30 mm deep is given in Fig. 3 after normalization. The incorporation of Jacobian weighing with dual mesh spatial prior information correctly recovers the lesion location.

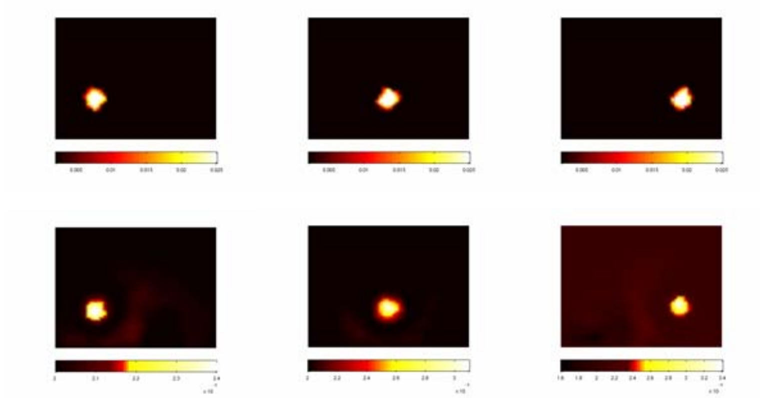
The Jacobian weighing leading to Fig. 2(d) is actually performed by weighing only at the suspicious lesion area. A validation of this approach is given in Fig. 4 where only one of the two suspicious lesions in (a) has absorption contrast (shown in (b)). A mesh with two denser element areas is generated for the two suspicious lesions of 10mm in diameter. The two lesions are all located in the middle plane. The images based on weighing the Jacobian in only the suspicious lesion areas is given in Fig. 4(c), where the only lesion with absorption contrast is correctly reconstructed.

The accuracy of recovering lesions in longitudinal dimension is given in Fig. 5 for 20mm depth lesion placing at 20mm, 40mm, and 60mm in axial dimension. Their positions are corrected reconstructed.



(a) (b) (c)

Fig. 4. Validation of partial Jacobian weighing approach



(a) 20mm (b) 40mm (c) 60mm

Fig. 5. Longitudinal reconstruction accuracy

4 Summary and Future work

It is shown that lesion depth up to 30mm may be correctly reconstructed by use of spatial prior and Jacobian weighing method when a sagittal imaging trans-rectal NIR probe of 60mm×20mm array dimension is used. Future work includes the use of a more realistic prostate model to account for prostate volume and rectal wall.

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