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Computational Performance of Time-Resolved Diffuse Optical Tomography in a Two-Layer Brain Model

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Abstract: We evaluate Mellin-Laplace algorithm in a two-layer brain model with Monte-Carlo generated data. Results show accurate absorption estimation and the flexibility of the algorithm to detect each layer thickness.

OCIS codes: 170.6920, 110.6955, 110.0113, 030.5260, 100.3190

1. Introduction

Traumatic brain injury (TBI) is one of the leading causes of disability and injury-related deaths. Although magnetic resonance imaging or computerized x-ray tomography are standard techniques in TBI treatment protocols there is still a need of a technology that could allow to perform bedside, continuous and non-invasive brain monitoring. Time-resolved diffuse optical tomography (TR-DOT) is an emerging photonics technology that could potentially permit to continuously measure important brain physiological values in TBI cases such as blood oxygenation levels.

Even though TR-DOT has already been applied, for example, to flap viability assessment [1] with very promising results there is still a lack of accurate optical properties estimation for brain imaging cases. Nonlinear Monte-Carlo fitting methods have been used in computational analysis [2] but their performance depends significantly on the knowledge of the geometry being scanned and is time consuming. In this work we computationally evaluate an algorithm based on Mellin-Laplace moments and we analyze its accuracy and adaptation to different layer thicknesses.

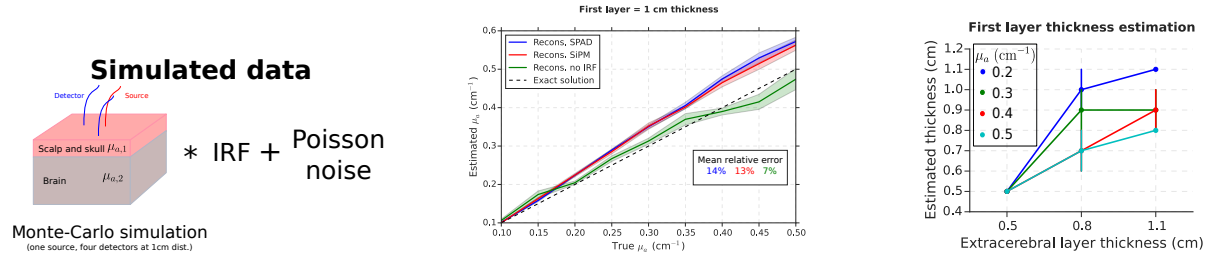
2. Method

The computational phantom consists of a two-layer model ($8 \times 8 \times 5 \text{ cm}^3$) containing an extracerebral and cerebral layer with one light source and four detectors placed at 1 cm distance at the top boundary, see Figure 1a. Monte-Carlo simulations [3] were performed on the phantom, signals were convolved with the instrumental response function (IRF) of single-photon avalanche diode (SPAD) and silicon photomultipliers (SiPM) detectors, and were corrupted with Poisson noise.

For the reconstruction of the optical properties, Mellin-Laplace moments algorithm [4] with twelve moments and $p = 9$ was used. This algorithm is based on finite element method and computes the moments of time-point spread functions in order to achieve a good balance between accuracy and computational time. The algorithm can be used on experimental data by performing measurements in a reference phantom; moreover, knowledge of the shape of the IRF is not necessary.

3. Results and Discussion

The first experiment consists in evaluating the Mellin-Laplace algorithm performance for estimating the absorption at cerebral layer. Monte-Carlo simulations were done with a constant absorption of $\mu_{a,1} = 0.1 \text{ cm}^{-1}$ at the extracerebral layer and an increasing absorption from $\mu_{a,2} = 0.1$ to 0.5 cm^{-1} on steps of 0.05 cm^{-1} for the cerebral layer. The scattering coefficient was maintained homogeneous along both layers because of its little sensitivity at brain layer [2]. Extracerebral and cerebral layer thicknesses were 1 cm and 4 cm respectively; homogeneous absorption through each layer was assumed. An homogeneous phantom of $\mu_a = 0.1 \text{ cm}^{-1}$ was taken as reference measurement. Results are plotted in Figure 1b for different types of detectors; they show that Mellin-Laplace algorithm reconstructs linear absorption estimations with low relative error. It is also seen that IRFs influence the results by yielding an overestimation



(a) Process for creating simulated data that mimics experimental data.

(b) Absorption reconstruction for simulated data with and without IRF. Confidence interval of 75%.

(c) Layer thickness estimation without using a priori data. Confidence interval of 75%.

Fig. 1: Results using Mellin-Laplace moments algorithm.

at absorption values much higher than the reference measurement making the relative error to increase twice with respect to free IRF data. No significant differences are seen in the performance with SPAD or SiPM detectors.

In the second experiment we aim to evaluate whether the algorithm is able to detect the thickness of the two layers; that is, whether the algorithm has the flexibility to adapt to the two-layer geometry when thickness of each layer is not given in advance. The domain was segmented in 0.3 cm-thick layers each of them with a homogeneous absorption. The two-layer geometry interface was estimated as the layer interface with largest absorption difference between above and below layers. Monte-Carlo simulations were performed for cases where extracerebral layer thickness ranged from 0.5 to 1.1 cm on steps of 0.3 cm; cerebral layer absorption ranged from $\mu_{a,2} = 0.2$ to 0.5 cm^{-1} on steps of 0.1 cm^{-1} . Results in Figure 1c show that accurate extracerebral layer thickness is estimated in 0.5 and 0.8 cm cases. Nevertheless, thickness is underestimated in 1.1 cm case because the algorithm has less sensibility to deeper layers. Higher absorption values tend to underestimate the thickness because the algorithm tries to compensate the high absorption by decreasing the extracerebral layer thickness.

4. Conclusions and Future Work

We studied the performances of a Mellin-Laplace algorithm for two-layer brain models with data that mimics realistic conditions. Accurate results are obtained if each layer thickness is given in advance although the algorithm is also capable of doing good estimations without that a priori information.

In the near future, we will extend the analysis by performing Monte-Carlo simulations on ATLAS head models and doing reconstructions of the absorption at the brain layer.

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