3D DOT Brain Imaging for Rhesus Monkey: An Anatomical Atlas-Based Method

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Introduction

Objective mapping of image findings to the underlying anatomy is becoming an essential capability for functional neuroimaging modalities. In the case of Diffuse Optical Tomography (DOT), complicating the goal of mapping activation findings to brain anatomy is the need for a representative atlas that can support the flexible generation of the required image operators for any selected optode arrangement. To facilitate accurate generation and mapping of DOT findings, we have developed an anatomical atlas-based method for DOT human brain imaging. In this report we will extend this computation-efficient method to imaging studies of the brain of a rhesus macaque. A hybrid rhesus monkey brain atlas is generated by the substitution of a population-average MRI-based brain atlas of the rhesus macaque for an individual rhesus monkey whole-head MRI scan. Evaluations of numerical simulations, phantom-based experiments and animal studies have shown that optode location, reconstruction of activation maps and mapping to the hybrid brain atlas can be made with high fidelity.

Methods

For accurate generation and mapping of DOT findings, we have developed an anatomical atlas-based approach for human brain imaging [1]. One of the key elements of the method is the established MR-based finite element method (FEM) model library that contains FEM meshes from a selected MR atlas that has been segmented according to different tissue types, which are use to generate pre-calculated image operators, as shown in Fig. 1. Using synthetic data, we examined the accuracy with which image finding are mapped to the correct brain structures and subsequently are mapped to an individual's MR image [2]. Fig.2 shows representative images reconstructed from simulation data.

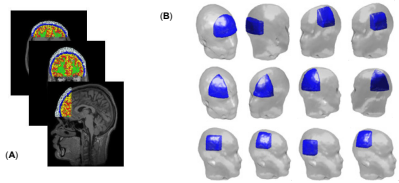

Figure 1. MRI-based segmented FEM brain mesh library.

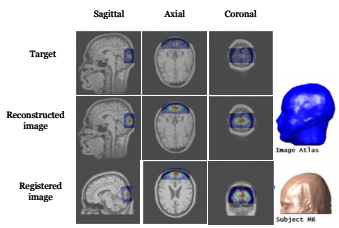

Figure 2. Reconstructed images from simulated data.

In this report we extend the atlas-based method to DOT rhesus monkey brain imaging.

Hybrid Rhesus Monkey Brain Atlas: To minimize subject bias, a hybrid rhesus monkey brain atlas was generated by substituting a population-average MRI-based brain atlas of the rhesus macaque (112 monkeys: 80 males, 32 females), available from the literature [3], for the brain component of an individual rhesus monkey (healthy, young, male) whole-head MRI scan, as shown in Fig.3.

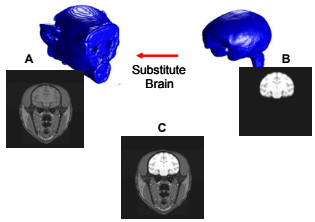

Figure 3. Hybrid brain atlas. (A) individual monkey head; (B) group-averaged monkey brain; (c) hybrid monkey atlas.

FEM Mesh and Image Generator: The hybrid map is segmented into six main classes—skin, muscle, skull, cerebrospinal fluid, gray matter, and white matter—for the generation of 3D FEM meshes, and the image generators are computed by numerically solving photon diffusion equation in tissues. Fig.4 shows the segmented FEM mesh and a FEM model with 64 sources and 64 detectors.

Image Reconstruction: 3D images of the Hb signal were reconstructed by using the normalized difference method [4]. This method solves a modified linear perturbation equation that is robust to many of the uncertainties common to experimental studies, including uncertainties associated with the initial guess, also known as the reference medium. Use of the linear approximation makes real-time 3D imaging feasible.

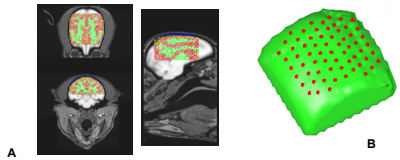

Figure 4. (A) Segmented FEM mesh of an optical imaging region; (B) An FEM model with 64 sources and 64 detectors.

Results

Qualitative and quantitative assessments of the fidelity of our method are presented in this section. Shown in Figure 5 is an example of our method applied to simulation data. Fig.5A shows the object position and Fig.5B the reconstructed images.

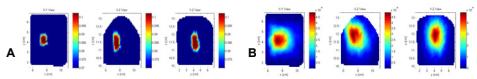

Figure 5. Results from simulated data. (A) Object position; (B) Reconstructed images.

DOT images reconstructed from phantom experiment data are presented in Fig.6. In this experiment a solid-state programmable monkey-brain phantom [5] with a 1x1x0.2 (cm^3) electrochromic cell (ECC), which is embedded in the left posterior brain at a depth of 1 cm below the head surface, was used to mimic the spatiotemporal hemodynamic pattern of interest. Shown in Fig.6A are reconstructed total hemoglobin maps, where the location of the ECC is accurately recovered. The reconstructed signal and its FFT at the cell's position are shown in Figs.6B and 6C, illustrating excellent recovery of the 1 Hz input signal.

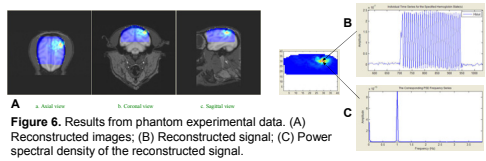

Figure 6. Results from phantom experimental data. (A) Reconstructed images; (B) Reconstructed signal; (C) Power spectral density of the reconstructed signal.

Fig.7 shows the results from animal-experiment data [6]. In the experiment, a Bonnet macaque was monitored using a CW-NIRS DOT imager with probes placed on the exposed skull in the mid frontal-parietal region, through an acute stroke and subarachnoid bleeding via occlusion of the internal carotid and middle cerebral arteries. Post-surgical CT-scan, MRI and brain histopathology revealed concurrence between subarachnoid bleeding, cortical infarction and interventional procedures (contrast, vasodilator injection) with NIRS findings.

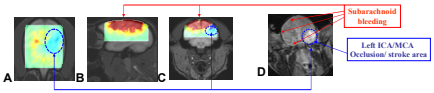

Figure 7. Results from animal experimental data. (A)-(C) Reconstructed total hemoglobin images; (D) MRI at the end of the experiment showing actual stroke area

Conclusions

In summary, we have developed an anatomical atlas-based method for generation and anatomical mapping of 3D DOT monkey brain image findings. As confirmed by numerical simulations, phantom experiment and animal experiment data, our method is computation-efficient and is able to carry out anatomical mappings with high spatial and temporal accuracy. The reported capabilities have been integrated into our NAVI computing environment [7] to support model-based fNIRS reconstruction and generation of MR-based montages.

References

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