

Three-dimensional Superimposition of Optical Tomography Results and Subjacent Anatomic Structures

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Abstract: We demonstrate the co-registration of three-dimensional activation volumes obtained from high density optical tomography of human brain function (1) with the individual's MR- scan and (2) with a generic brain model.

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1. Introduction

Near Infrared Spectroscopy (NIRS) is an established tool for revealing cortical activation through changes in the degree of hemoglobin oxygenation in the activated area. Near infrared light is injected into the subject's brain by optical fibers, which are placed on the subject's head surface.

Spatial resolution can be enhanced by a multi-distance approach [1, 2]. Arrays of closely spaced fibers allow the simultaneous measurement of light paths from different tissue depths. This three-dimensional optical tomography (OT) leads to a rough depth discrimination and facilitates the separation of signals from superficial and deeper layers. As NIRS itself reveals no information about underlying anatomical structures, an independent anatomical mapping is desirable, especially when regions prone to large inter-subject variability are studied. In this work we show two ways to match OT data from high density fiber grids to anatomical structures without calculating individual optical forward models.

First, we show a co-registration of the OT result volume with the individual's anatomical magnetic resonance (MR-)Scan, and secondly we show the mapping onto a generic brain model for instances where an individual MR-Scan is not available.

2. Methods

Healthy voluntary subjects performed a left finger tapping task. Neural activity was measured with a rectangular grid (3.0 x 3.75 cm) of 30 optical fibers over the contralateral peri-central area. Each fiber served as source and detector, facilitating the acquisition of 900 simultaneous optical data channels using the DYNOT 232 optical tomography imager (NIRx Medizintechnik GmbH, Berlin). From these we reconstructed volumetric image time series of oxy- and deoxy-hemoglobin concentration changes using the approach described in [1]. The algorithm achieves fast image reconstruction by inversion of a pre-calculated image operator, which is generated by solving the diffusion equation on a Finite Element Method (FEM) mesh which was obtained from a standard MR image [3].

We show two ways of co-registering volumetric OT results with anatomic scans. For the first method (Fig.1) we indicated the corner positions of the imaging grid on the scalp with fiducial marks and acquired anatomical MR scans. Using the SPM8 (The Wellcome Trust Centre for Neuroimaging, University College London) spatial preprocessing tool, we normalized the subject's anatomy, using the MR scan on which the FEM model was based as a template. This resulted in a nonlinear transformation of the subject's head anatomy without losing structural information. The translocated positions of the fiducial marks were determined and assigned to the FEM model that was used for optical image reconstruction (Fig. 2 E). We used a general linear model (GLM) to reveal functional activation patterns in the reconstructed time series, and finally superimposed this volume onto the individual's MR scan.

The second method (Fig.2) requires no structural scan of the subject. Coordinates of 19 reference points (international 10-20 system) and of the four corner positions of the optode pad on the subjects head surface were recorded using photogrammetric software (PhotoModeler, Eos Systems Inc., Vancouver, Canada). Employing the Horn algorithm [4] we solved the least-square problem of superimposing the reference points and the corresponding model coordinates using affine transformations (translation, rotating, and scaling).

We then translocated the fiber positions onto the FEM mesh, thereby ensuring the correct position of the reconstructed images. The resulting volumes were then superimposed onto the generic anatomy of the model scan.

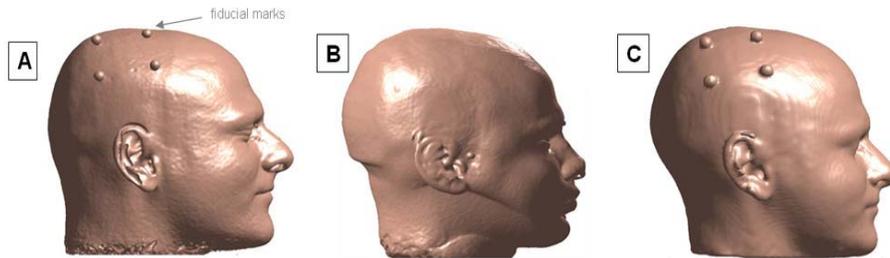


Fig. 1 Transformation of the pad corner positions from individual MR scan to the FEM model space. A) MR scan of one subject. Corner positions of the probe pad (four spheres) were marked with vitamin E pills for a good contrast. B) MR scan of the generic brain model. This scan is the basis for the FEM model library with precalculated inverse parameters. C) Subject's MR image after a nonlinear transformation (using SPM8) with the generic brain model (B) serving as template. The subject's head shape and localization now matches the model's while anatomical structures are preserved. Fiducial marks on subject's head surface were likewise transformed to the model space.

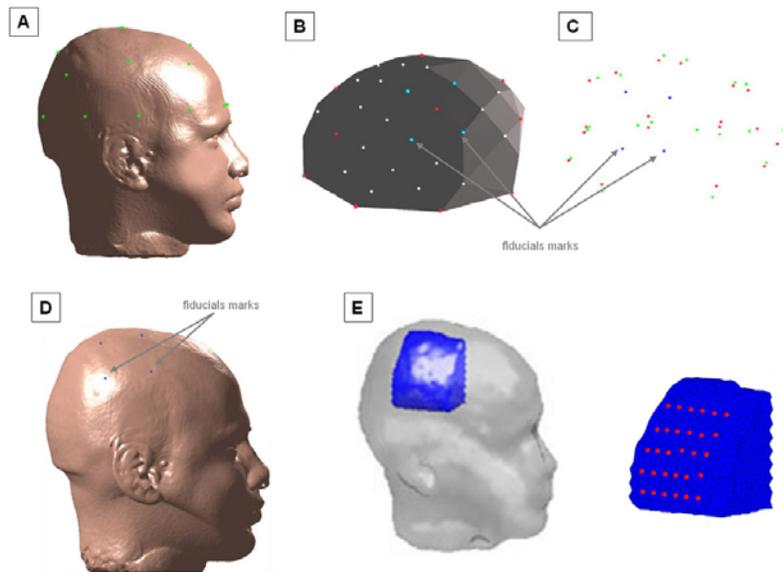


Fig. 2 Transformation of the pad corner positions to the FEM model space without individual MR scan. A) MR scan of generic model with 19 marked reference points (green dots) derived by [5]. B) 19 reference points (red dots) and fiber pad coordinates (blue dots) were acquired from the subject's head surface using photogrammetry. C) Affine Transformation of the subject's reference coordinates to the model's 10-20 positions. D) As the marked pad corners are now in the generic model space, the positions (blue dots) can be mapped on the model's head surface. E) For optical reconstruction, we chose the optode positions in the FEM model to match the location of the imaging pad so as to ensure the correct position of the result volume. This step is also performed when using the first method.

3. Results

Images were reconstructed on a sub-volume of the FEM mesh covering the region of the probe array on the subject. For the finger tapping task a GLM was calculated to assess the effect of hemodynamic changes within this specific sub-volume. A design matrix consisting of a 0–1 boxcar predictor was convolved with a hemodynamic response function with a peak at 5s.

We show volumetric activation patterns (t-values < -3) for deoxygenated hemoglobin) for one subject. We superimposed the result volume on both the individual MR scan and the generic head model. We achieved a good overlap of the OT activation with the cortex structures known to represent motor control. We obtained good results for both mapping the pattern with the generic brain and registering the OT results to individual MR scans.



Fig. 3 Volumes of t-values (< -3) for deoxygenated hemoglobin (red) are superimposed on A) the subject's brain and B) the generic brain model

4. Conclusions

NIRS and diffuse optical tomography reveal cortical activation but cannot resolve underlying anatomical structures. For optical topography a method of probabilistic mapping has been applied by [6].

For optical tomography, first the photon propagation in tissue is simulated, and then the inverse problem is solved to reconstruct internal absorption changes from optical surface measurements. Recently, volumetric mapping of functional OT data has been demonstrated using forward models considering the individual's brain morphology [7]. This approach is computationally burdensome for high-density grids and large numbers of channels and subjects. Instead, we use one generic, pre-calculated light propagation model in conjunction with individual anatomical superimposition. We demonstrate successful mapping onto individual brain scans or a generic atlas, which we deem most desirable for studying brain areas of great structural and functional individuality.

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