MethodsX 1 (2014) 275–282

Contents lists available at ScienceDirect

MethodsX

journal homepage: www.elsevier.com/locate/mex

Head movement compensation in real-time magnetoencephalographic recordings

Graham Little [a], Shaun Boe [c], Timothy Bardouille [a,b,c,d,*]

[a] Biomedical Translational Imaging Centre (BIOTIC), IWK Health Sciences Centre, Halifax, Nova Scotia, Canada
[b] Department of Diagnostic Imaging, IWK Health Sciences Centre, Halifax, Nova Scotia, Canada
[c] Laboratory for Brain Recovery and Function, School of Physiotherapy, Dalhousie University, Halifax, Nova Scotia, Canada
[d] Department of Computer Sciences, Dalhousie University, Halifax, Nova Scotia, Canada

ABSTRACT

Neurofeedback- and brain-computer interface (BCI)-based interventions can be implemented using real-time analysis of magnetoencephalographic (MEG) recordings. Head movement during MEG recordings, however, can lead to inaccurate estimates of brain activity, reducing the efficacy of the intervention. Most real-time applications in MEG have utilized analyses that do not correct for head movement. Effective means of correcting for head movement are needed to optimize the use of MEG in such applications. Here we provide preliminary validation of a novel analysis technique, real-time source estimation (rtSE), that measures head movement and generates corrected current source time course estimates in real-time. rtSE was applied while recording a calibrated phantom to determine phantom position localization accuracy and source amplitude estimation accuracy under stationary and moving conditions. Results were compared to off-line analysis methods to assess validity of the rtSE technique. The rtSE method allowed for accurate estimation of current source activity at the source-level in real-time, and accounted for movement of the source due to changes in phantom position. The rtSE technique requires modifications and specialized analysis of the following MEG work flow steps.

- Data acquisition
- Head position estimation
- Source localization
- Real-time source estimation

This work explains the technical details and validates each of these steps.

ARTICLE INFO
Method name: Real-time Source Estimation (rtSE)
Keywords: Brain computer interface (BCI), Magnetoencephalography (MEG), Neurofeedback, Real-time analysis
Article history: Received 26 June 2014; Accepted 21 October 2014; Available online 3 November 2014

Method details

Data acquisition

The calibrated phantom (ElektaOy, Finland) contains 32 current sources of known position and orientation and four HPI coils inside a hemisphere casing. Sinusoidal currents tangential to the hemisphere casing can be driven at each source location independently to generate an alternating magnetic field on the MEG sensors. Eight superficial current sources (i.e., at a distance of 64 mm from the phantom origin) were selected for use in this study. The selected current sources allowed for maximum spatial disparity between sources, to investigate activation across the sensor array. These sources can be localized

* Corresponding author at: MEG Lab, 1st floor Goldbloom Pavilion, IWK Health Centre, P.O. Box 9700, Halifax, Nova Scotia B3K 6R8, Canada. Tel.: +1 902 470 3936; fax: +1 902 470 6767.
E-mail address: tim.bardouille@dal.ca (T. Bardouille).

http://dx.doi.org/10.1016/j.mex.2014.10.008
2215-0161/

with millimeter accuracy based on the MEG data using a current dipole model [1]. The HPI coils on the phantom are wire loops that can be activated to generate a magnetic field source that is easily localized by the MEG sensor array. Before the MEG acquisition, the positions of the HPI coils were digitized using the FASTRAK digitization system (Polhemus, USA). The phantom was then secured in a stationary position under the MEG helmet with the capacity to manually adjust the position of the phantom during the scan to simulate head movement.

All data was acquired on a MEG system containing 204 planar gradiometers and 102 magnetometers (ElektaOy, Finland). The MEG system is housed in a lightly shielded room, which utilized active shielding to eliminate environmental magnetic interference (MaxShield; ElektaOy, Finland). Data were sampled at 1000 Hz with a bandwidth of 0.10–330 Hz, and recorded to a file for off-line analysis. Event markers indicating the onset of phantom current source activation were recorded concurrently.

Simultaneous with the off-line file recording, one-second MEG data segments were transferred to a real-time analysis computer for immediate analysis. Real-time analysis of MEG data was performed using the Matlab software environment (version 7.10.0.499 R2010a, Mathworks, USA) installed on an HP Desktop Computer, running Ubuntu version 12.04. The software for real-time data transfer was provided by the Fieldtrip toolbox [2]. This open source toolbox (version 20110727) was installed on both the Elekta MEG acquisition workstation, and the real-time analysis computer. The technical aspects of the real-time data transfer server and client, including selection of variable data segment lengths, have been described previously [3].

Only the 204 planar gradiometers were analyzed in real-time. The magnetometers were active during acquisition to facilitate active shielding. Magnetometers were not included in the real-time analysis for two reasons. Firstly, the magnetometers are more susceptible to environmental interference than the planar gradiometers. This interference can be attenuated via signal space separation (SSS) [4]. However, the SSS algorithm was not implemented in the real-time analysis described in this paper due to the significant processing power requirements. Secondly, the SSS algorithm also attenuates distortions of the measured magnetic fields due to the active shielding. This distortion is essentially isotropic across any given planar gradiometer sensor, and thus has no net effect on the measured signal. As such, active shielding mainly distorts the magnetic field data at magnetometer sensors and the effect is negligible on planar gradiometers.

At the start of the study, a short (10 s) "localizer" scan was recorded with the phantom in a stationary position. The HPI coils were activated continuously during the collection at unique driving frequencies between 293 and 321 Hz. No current sources were activated during this scan. This localizer dataset was passed to the real-time analysis computer to establish an initial high-resolution HPI coil localization. Specifically, the HPI localization data was read from the localizer data file using custom software created in the C programming language with a vendor supplied C interface which implements basic file input–output operations on Elekta formatted data files. Following this, Experiment 1 tested the accuracy of the real-time analysis for HPI coil localization. MEG data were collected for 326 s with the phantom in a stationary position, all HPI coils active, and no current source active. Experiment 2 tested the accuracy of the real-time analysis for current source localization. The phantom remained in a stationary position with all HPI coils active. During this scan, each of the eight superficial current sources was consecutively activated with 2 cycles of a 20 Hz sinusoid every 350 ms at a magnitude of 1000 nAm for 100 s. Experiment 3 tested the accuracy of HPI coil localization and source estimation during real-time analysis in the movement condition. All HPI coils and a single current source were activated. In this scan, after 10 s of baseline data were collected, a technician inside the magnetically shielded room moved the phantom once every 10–20 s to approximate sustained head translations and rotations of several centimeters and degrees, respectively. The speed and magnitude of the movements were on a similar scale to those reported in challenging human cases [5]. Also, the largest possible current source magnitude was used to provide a maximal signal-to-noise ratio at the MEG sensors for measuring small changes in estimated source strength induced by movement.

Data analysis – head position estimation

Head position estimation occurred in the localizer scan and all three experiments. For each one-second data segment passed to the real-time computer, we calculated the magnetic field strength generated at each sensor due to the activation of each HPI coil. First, a cross-talk correction matrix was applied to the MEG data to eliminate cross-talk interference between sensors [6]. For each sensor, the data were then baseline corrected based on the mean amplitude over the data segment. Following this, a continuous signal decomposition was performed at each coil frequency to determine the sine (real) and cosine (imaginary) component of the decomposition of the magnetic field due to each HPI coil [7]. At each coil frequency, the two components for all sensors were plotted to a complex plane, and a linear regression of these data was performed. Real values indicating magnetic field strength at the coil frequency were determined by projecting the components for each sensor to the linear regression. For each HPI coil, the resultant estimates of magnetic field strength across the sensors defined the "measured" MEG field data.

Using the last one-second data segment collected in the localizer scan, the rigorous fitting method described below was applied to each HPI coil to provide accurate estimation of coil position, orientation and magnitude. The resulting parameters for each coil defined a rigid body, with the relative positions, orientations and magnitudes of all HPI coils fixed. For the rigorous fitting method, an unconstrained multivariable optimization algorithm (Nelder–Mead simplex direction search) [8] was applied to the final one-second data segment to estimate six parameters (x, y, z, location; x, y, z magnitude/orientation) for each HPI coil. The initial parameters for the optimization were provided by the acquisition software's initial head position