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A Comparison of Five Free Software Solutions for Generating Realistic Human Head Models from Magnetic Resonance Imaging

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Abstract

A set of five free software solutions for generating realistic human head models from subject-specific MRI data are compared. Boundary Element Method (BEM) is used for realistic modelling. Software tools that can perform the MRI segmentation and can generate BEM surfaces or meshes for those segments are selected for comparison. Performances of those software tools are analysed and compared based on their declared characteristics and outcomes after real MRI data analysis. MRI scans of five different subjects are used for comparative analysis. Obtained results can assist the users in choosing the appropriate software tool that can meet their particular needs.

1 Introduction

A computer model of human head is inevitable for the automatic source localization of Electroencephalogram (EEG) and Magnetoencephalogram (MEG) signals. Head model based EEG/MEG source localization can be used for the analysis and diagnosis of various neurological disorders, such as Epilepsy [1] and Alzheimer Diseases [2]. Anatomically realistic and subject specific head models are essential for the accurate localizations of EEG/MEG sources. Realistic head model of a subject can be generated from the Magnetic Resonance Imaging (MRI) scans of subject's head. A variety of software solutions, both free [3,4,5,6,7] and commercial (e.g. BrainVoyager QX, BESA MRI, and CURRY), are available for generating realistic subject specific head models form individual subject's MRI scans. Each of these software tools has certain advantages and limitations. Critical comparisons of these software tools are very important for selecting the most suitable one for a particular use.

A few studies compared the software tools that are used for MRI segmentation and surface generation. Tsang et al. [8] provided a quantitative analysis and comparison of the segmentation algorithms of two software tools, namely Statistical Parametric Mapping (SPM) [9] and FMRIB Software Library (FSL). Klauschen et al. [10] compared three widely used brain volumetry methods available in the software packages FSL, SPM5, and FreeSurfer. They evaluated the performance using simulated and real brain MRI data sets and their study was focused on the accuracy of volume measurements and the robustness against changes of image quality. Recently, Kazemi and Noorizadeh [11] investigated the accuracy of three software packages SPM, FSL and BrainSuite for brain tissue segmentation. All of these comparative studies were mostly focused on the underlying algorithms and concepts of the selected software tools and were less concerned about usability issues.

This paper investigates the usability and practicality of five widely used software tools for head MRI segmentation and surface generation and also compares their significant characteristics from normal user's perspective. The selected software packages investigated are: FieldTrip [3], Neuroelectromagnetic Forward Head Modeling Toolbox (NFT) [4], BrainVISA [5], BrainSuite [6], and FreeSurfer [7]. FieldTrip actually uses the latest version of SPM software at the backend for MRI segmentation but it has its own mesh generation module.

These five software tools are selected because they are open-source and/or free and run on Windows operating system. Surface generation techniques and underlying numerical methods are also considered. Common numerical methods, employed for developing realistic head models, are Boundary Element Method (BEM), Finite Element Method (FEM), and Finite Difference Method (FDM) [12]. FEM and FDM provide more realistic models but consume more computation time and memory. Therefore the implementation of FEM and FDM toolboxes are mostly in experimental level. In this context the software tools that can generate BEM surfaces or meshes of the segmented MRI regions are selected for this study.

Brief description of the selected software tools and the dataset used are given in the next section. The results of comparative analysis are described in the Results section. Finally, the conclusion is given in the last section.

2 Methods and Materials

2.1 MRI Segmentation and Surface Generation

FieldTrip Head MRI segmentation is an image processing operation. Its goal is to separate each MRI scan of a subject into a number of different homogeneous regions where each region corresponds to a particular type of tissue of the subject's head. Automatic MRI segmentation tools, used for EEG/MEG source localization, usually separate three or more types of tissues. Typically segmented tissue types are scalp, skull, cerebrospinal fluid (CSF), white matter (WM) and grey matter (GM). BEM based head modelling algorithms use only the surfaces of these segmented tissue regions rather than their total volumes. Mesh generation modules of the head modelling software tools use the results of the segmentation and create triangular meshes that fit the boundaries of the segmentation. Some features of the selected software tools are briefly discussed below.

2.1.1 FieldTrip

FieldTrip is an open-source Matlab-toolbox for source analysis of oscillatory electromagnetic activity (MEG and EEG) of brain and was developed by the Donders Institute for Brain, Cognition and Behaviour, University Nijmegen, Netherlands. This software package can be downloaded from http://fieldtrip.fcdonders.nl/download.

2.1.2 NFT

NFT is also an open-source MATLAB toolbox. It can generate realistic head models from available data (MRI and/or electrode locations) and can compute numerical solutions for the forward problem of EEG/MEG source localization. NFT uses some third party tools and libraries for segmentation and mesh generation: ASC for triangulation of 3D volumes, Qslim for mesh coarsening and Matitk - Matlab interface to the ITK image processing toolkit. Source code of NFT is available at http://sccn.ucsd.edu/nft/install.html.

2.1.3 BrainVISA

BrainVISA offers several features such as: Workflows and pipelines, Graphical user interface, Visualization, Massive computation facilities, Toolboxes [13]. Application field of BrainVISA is extremely wide, because virtually any software can be integrated with this software tool [14]. It is developed by a French federative research institute: IFR 49. It is an open-source software written in Python script language and can be downloaded from: http://brainvisa.info/download.html.

2.1.4 BrainSuite

BrainSuite is a collection of image analysis tools designed to process MRI of the human head. It is free but not open source. It can extract cortical surface mesh models from the MRI. It provides tools for registering these surfaces to a labelled atlas, for processing diffusion imaging data, for visualization of these data, and for interactive mapping of regional connectivity. BrainSuite is collaboratively developed by Ahmanson-Lovelace Brain Mapping Center at University of California, Los Angeles and Biomedical Imaging Group at University of Southern California, Los Angeles. The latest version of BrainSuite is available for download from http://brainsuite.org/download/.

2.1.5 FreeSurfer

FreeSurfer Software Suite is an open source software suite for processing and analyzing human brain MRI images. Skull stripping, image registration, subcortical segmentation, cortical surface reconstruction, cortical segmentation, cortical thickness estimation, longitudinal processing, fMRI analysis, tractography, FreeView visualization GUI, etc. are the mentionable features of FreeSurfer. This software tool was developed at the Martinos Center for Biomedical Imaging by the Laboratory for Computational Neuroimaging. FreeSurfer executables are available for download from http://surfer.nmr.mgh.harvard.edu/fswiki/Download.s

2.2 Dataset

T1 weighted MRI scans of five different subjects (3 females and 2 males and aged between 20 and 40) are used for comparing the performances of the selected software tools. These MRI scans are obtained from Neuroimaging Informatics Tools and Resources Clearinghouse Image Repository (NITRC-IR) [15]. All datasets are anonymous, de-identified and with no protected health information included. Other acquisition parameters are as follows: Field Strength - 3T and Voxel Resolution (mm) - 1.0 x 1.0 x 1.0. File format of all the MRI scans is gz compressed NIFTI-1 image (*.nii.gz).

3 Results

Comparative investigation of five selected software tools, for MRI segmentation and surface generation, are carried out based on their declared features and real data analysis outcomes.

3.1 Comparison Based on Stated Features

Published articles and official webpages of the selected five software tools declared various features of those tools. Some of these features that are important for general users are compared in this subsection. System requirement is an important feature before starting work with a software tool. Table 1 lists the system requirements of the selected software tools. It shows that all the tools can run under Linux Operation System (OS), but MATLAB should be there for running FieldTrip and NFT. BrainVISA is not tested on the latest versions of Windows. Practically, BrainVISA is found malfunctioning on Windows 8.1 OS. Moreover NFT and FreeSurfer recommends highest amount of system memory for proper operation.

Table 1: System requirements of the selected tools.

Software Tool	Minimum System Requirement	
	Operating System (OS)	System Memory
FieldTrip	Run under MATLAB platform that is running under any OS.	Not specified. Depends on size of data.
NFT	Run under MATLAB 7.0 or later that is running under any OS.	At least 2 GB (4-8 GB recommended)
BrainVISA	Tested and found functional on Linux (Ubuntu 10.04, Fedora 4-9, RedHat 9, Mandriva 2007 & 2007) Mac OS (10.4 & 10.5), Windows (XP, NT, 2000).	Not specified. Depends on the size of data.
BrainSuite	Windows and Mac OS. BrainSuite Diffusion Pipeline (bdp) also run under Linux.	bdp requires 6 GB
FreeSurfer	Linux, Mac OS, Windows (via VirtualBox only).	8GB (recommended)

MRI scans could be available in various data formats. So, knowing the input and output file formats are also important for the users. Table 2 presents the MRI file formats that are supported by the selected tools. It shows that BrainVISA and FreeSurfer provide huge flexibility in MRI data format. In fact these two tools have their own built-in MRI converters. NFT can work on Analyze format only and recommends to use FreeSurfer's MRI converter for MRI preparation. This table also lists the file formats of the generated BEM meshes/surfaces.

Table 2: Input and output file formats.

Software Tool	Supported MRI Formats	Generated BEM Surface File Format
FieldTrip	CTF - VSM MedTech, NIFTi, Compressed NIFTi, Analyze, DICOM, AFNI, FreeSurfer, MINC, Neuromag – Elekta, ANT, Yokogawa	MATLAB (*.mat)
NFT	Should be in Analyze format and the voxel size should be (mm) 1×1×1.	*.smf & *.mat
BrainVISA	PNG image, XBM image, XPM image, TIFF image, TIFF(.tif) image, PPM image, GIF image, JPEG image, BMP image, PBM image, PGM image, MNG image, SPM image, GIS image, VIDA image, ECAT v image, ECAT i image, DICOM image, MINC image, compressed MINC image, NIFTI-1 image, compressed NIFTI-1 image	*.gii & *.minf
BrainSuite	Works best with NIfTI format, but also provides limited support for DICOM images.	*.dfs
FreeSurfer	MGH-NMR COR, MGH-NMR MGH-NMR (compressed), MNI's Medical Imaging NetCDF, 3D analyse, 4D analyse, SPM Analyze, GE Genesis, GE LX, GE XIMG variant, Siemens IMA, generic DICOM, Siemens DICOM, AFNI, MGH-NMR bshort, MGH-NMR bfloat, MGH-NMR Outline, GDF volume, NIfTI-1, compressed NIfTI.	*.curv

3.2 Comparison Based on Real Data Analysis

FieldTrip, NFT and BrainSuite are installed and operated properly under Windows 8.1 OS. FreeSurfer needs ORACLE VM VirtualBox support, with guest OS Xubuntu 12.04, for running on the same machine. Processor speed and system memory of this machine are 2.40GHz (Intel Core i7) and 16GB respectively. Since BrainVISA doesn't run properly on Windows 8.1, it is installed in a different computer having Windows XP OS. This machine has 1.80GHz Intel Core 2 Duo processor and 2GB system memory. All of the five selected software tools are used for generating BEM meshes/surfaces from each of the five MRI datasets.

BrainSuite and FreeSurfer generate simulation results for all of the five datasets and without any error message. During outer skull segmentation, NFT tries to remove the eyeball regions from the skull. The eyes are extracted by region growing from the user-indicated points [4]. Since some parts of the eyeball regions of the selected datasets are removed during de-identification process, NFT gives an error message while segmenting the outer skull. Simple modification of NFT code, i.e. omitting that error message generation instruction, can make it functional. After this modification, NFT performs the segmentation and surface generation tasks for all of the five datasets. FieldTrip crashed while simulating the MRI dataset of 5th subject only, whereas BrainVISA crashed on processing 2nd and 5th subjects' datasets. 3rd set of MRI data, which is successfully processed by all of the five software tools, is shown in Figure 1.

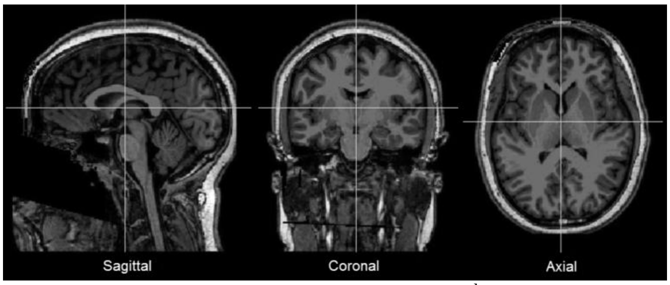

Figure 1: MRI scan of a subject (3rd dataset).

All the default parameters and settings of the software tools, except the number of vertices of NFT, are kept unchanged during both segmentation and surface generation processes. With default parameters and settings FieldTrip and BrainSuite generate five surfaces (scalp, skull, CSF, WM and GM) for each MRI dataset. WM is not segmented by NFT. It produces brain surface which actually resembles the GM. BrainVISA and FreeSurfer do not produce skull and CSF. These tools are more concern about cortical surface generation. Figure 2 illustrates all the surfaces generated by all of the five software tools from the same MRI dataset that is shown in Figure 1. From visual observation it can be stated the scalp, GM and WM generated by BrainVISA look most realistic. Besides, skull and CSF images produced by NFT look more accurate. FieldTrip generated surfaces are sometimes incomplete or inaccurate as shown in Figure 2.

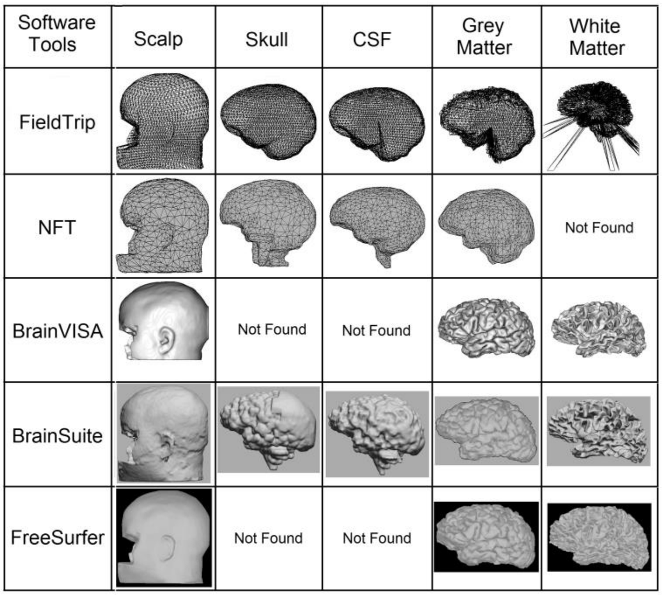

Figure 2: Surfaces generated from 3rd MRI dataset.

Among all the software tools, FreeSurfer and BrainSuite can perform the MRI segmentation and surface generation processes without any user's feedback. FieldTrip needs user's feedback for finding the orientation of the input MRI. For brain segmentation through NFT, user should select the lowest point of the cerebellum and a WM seed point manually. Moreover, for outer skull segmentation, NFT needs to read the centre of eyeballs from the user. For using BrainVISA, user should provide the coordinates of the anterior commissure, posterior commissure, interhemispheric point and the left hemisphere point or should select those points on MRI scans.

Execution times of the selected software tools are not included in the comparison, because the tools run on different hardware and operating systems. Moreover, the number and types of operations are different from one tool to another.

4 Conclusion

Five well known free software tools for MRI segmentation and BEM surface generation have been compared. Obtained result shows that none of the tools can be considered as the best. Ranking of the tools depends on the user's needs. If less resource (hardware and software) is available, then BrainVISA would be the best choice. If number of tissue classes for analysis is important, then Brainsuite would provide the best. Some application demands most of tissue class analysis as well as source code customization. For such cases, FieldTrip would be a good option, because BrainSuite is not an open-source tool. If more accurate skull surface is vital, then NFT would be the best option. Latest application areas mostly need accurate and reliable cortical surface generation. FreeSurfer can meet that need. For choosing the right tool users should know the strengths and limitations of these tools. So this comparative study of the latest tools with practical implementation results would be a helpful guide for the users. In future more in-depth analysis of all the available software tools can be carried out. This paper would lay the foundation of such future work.

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