NAVI: A Problem Solving Environment (PSE) for NIRS Data Analysis

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OVERVIEW

What is NAVI?

Growing interest in NIRS (near-infrared spectroscopy) imaging is generating an increasing demand for an integrated computing environment capable of exploring the richness and complexity of spatiotemporal measures of blood delivery to tissue. As with other complex systems, key to their study is a problem-solving environment (PSE) that allows for the description, discovery and analysis of relevant phenomenology in ways that retain computational efficiency and facilitate file management. NAVI, (**N**ear-infrared **A**nalysis, **V**isualization and **I**maging), is a rich constellation of instrument performance monitoring, filtering, image formation, feature extraction, visualization, statistical analysis, and file and database management tools for the examination of functional NIRS data.

NAVI utilizes the MATLAB run-time component and is distributed as a stand-alone program for Windows® or Linux. NAVI offers point-and-click navigation and visualization of data within a flexible file management system that employs wizards to facilitate group data loading, batch processing, automated file system creation, and recording of parameter settings used in data processing. Image visualization is available through a variety of styles and makes generous use of montage formats for the overlay of multi-feature information.

By optimizing the balance between computational effort and computer memory, together with use of fast algorithms, NAVI enables the analysis and visualization of large-scale data sets. In addition, NAVI's image conversion function allows the export of NAVI-generated images into standard image formats for use with other software packages such as SPM, Medx, AFNI and GiD.

Figure 1 shows a screenshot of the NAVI home user interface, which comprises four principal portals: **Image Generator**, **Data Viewer**, **Data Analyzer**, and **Extended Utilities**. Each of the key features included in the software package is discussed in the following section.

MAIN FEATURES

File Management and Electronic Ledger

Two key elements of the NAVI design are the incorporation of an automated file generation system and its use of electronic ledgers. Having loaded raw data from the scanner once, thereafter all file generation and management is achieved through a single file that is integrated with a background database. Data loading for viewing and analysis is achieved efficiently and without the need to navigate using the typical approach of an ever-expanding, user-generated file tree structure.

The electronic ledger keeps track of all facets of data generation, including instrument scanning parameters, FEM mesh details, and selected parameters used for data filtering, editing, feature extraction, etc. In short, all of the particulars needed to uniquely define the operations used for all steps of data processing are stored automatically in an organized and easily accessible format.

Image Generator

The Image Generation portal allows for filtering and normalization of the raw wavelength time series and computation of hemoglobin states (oxy-, deoxy-, total-Hb, HbO_2 saturation). It also provides for specification of different linear reconstruction methods (truncated SVD, LU decomposition) for recovery of wavelength-dependent absorption and scattering coefficients and Hb states,[1] access to stored FEM mesh libraries, toolboxes for generating a FEM meshes from anatomical priors or other user-definable media, a diffusion-based DC forward solver for computation of surface intensities and Jacobian operators, as well as access to an image enhancement scheme[2,3] described in other abstracts at this meeting. Figure 2 shows some user interfaces used for and results derived from Image generator.

Data Viewer

The data viewing portal provides for a broad range of viewing options, editing, and storage that can be applied to detector-channel and to 2D or 3D volume-rendered image data. Included are options for generation of movies, display of selected or complete channel/pixel time series, montage formats, display of image data in an axial, coronal or sagittal view, and extraction of the data-processing information and the saved results [see Figures 3–5(a)]. In addition, the data viewing portal provides a file format conversion tool that allows users to export NAVI-generated data in a number of different formats. The available formats make it possible for users to edit, view and analyze the exported data with other, commonly available software packages, such as AFNI, SPM, or GiD [see Figure 5(b)].

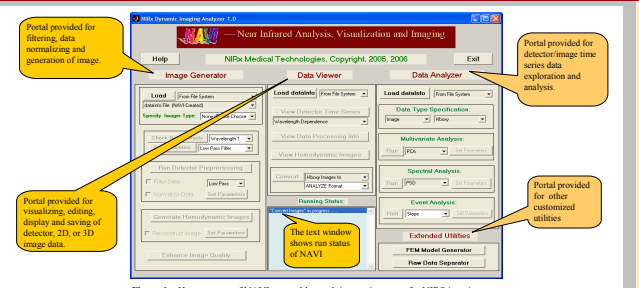

Figure 1. Home screen of NAVI—a problem solving environment for NIRS imaging.

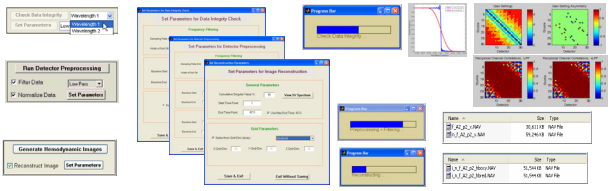

Figure 2. User interfaces for detector processing and image reconstruction.

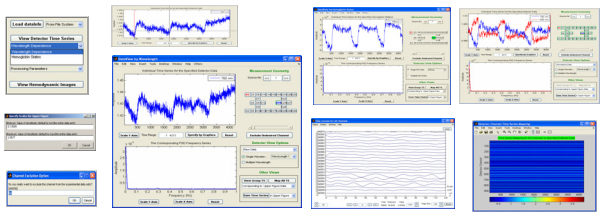

Figure 3. User interfaces for viewing detector time series in NAVI.

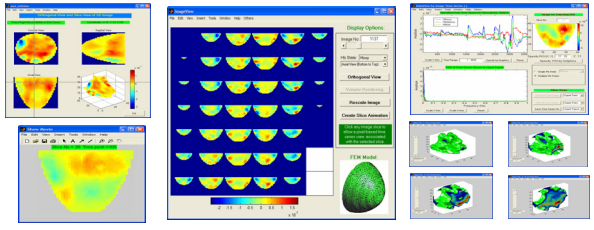

Figure 4. User interfaces for viewing dynamic hemoglobin images in NAVI.

Data Analyzer

The data analysis portal provides feature extraction capabilities for blind or model driven signal separation (Principal Component Analysis, Molgedey-Schuster Analysis, Independent Component Analysis, General Linear Model), spectral analysis (Power Spectral Density, Cross Spectral Density, Coherence, Time Correlation, Wavelet), and event analysis (slope, time-delay, Area Under Curve). Exemplary screens shots employing PCA, Cross correlation and slope analysis are shown in Figure 6.

Under development are toolboxes for uni- and multi-variate analysis that will allow for generation of statistical parametric maps. Also being developed is an integrated, web-accessible and secure SQL open source database, originally developed by investigators at McGill University (OSCAR), to allow for data sharing between investigative teams.

Figure 7 shows results generated by using AFNI with imported NIRS time series images that were derived from a DYNOT-based experimental data from a verbal working memory study in health adults.

Extended Utilities

The functionalities provided by the Extended Utilities portal give experienced users of DYNOT imaging systems greater flexibility, in terms of designing and testing novel arrangements of scalp optical fibers for brain imaging studies. The FEM Model Generator function allows the user to create the mathematical operators required for image reconstruction, when the number and/or locations of fibers do not match any of the models provided with NAVI [see Figure 8(a)]. The Raw Data Separator function allows the user to design experiments that call for placement of optical fibers on two distinct regions of the scalp (*e.g.,* left and right motor cortices, prefrontal and motor) [see Figure 8(b)].

CONCLUSIONS

We have developed a versatile problem solving environment that provides for the efficient and bulk processing of large scale NIRS data files. Available capabilities include: image generation, image enhancement, feature extraction and statistical parametric mapping, multiple display and data editing capabilities, automated file management system and an electronic ledger.

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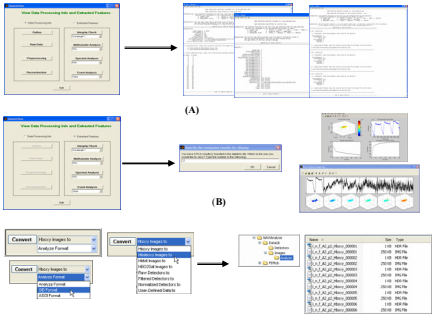

Figure 5. User interfaces, and the corresponding output, for (A) viewing data processing Info, (B) viewing extracted features, and (C) NAVI-generated file format conversion.

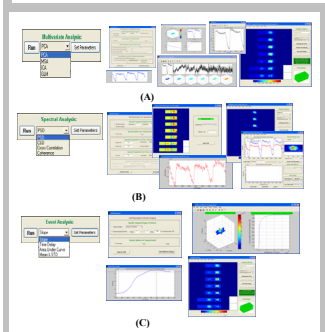

Figure 6. User Interfaces, and the corresponding results, for (A) PCA, (B) CSD analysis, and (C) Slope analysis.

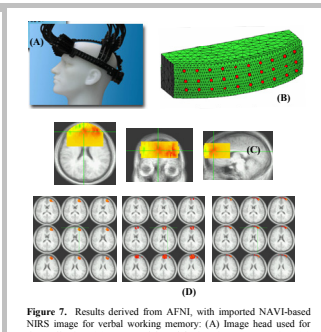

Figure 7. Results derived from AFNI, with imported NAVI-based NIRS image for verbal working memory: (A) Image head used for data collection; (B) FEM model used for imaging reconstruction; (C) NIRS images overlain onto a brain template; (D) oxy-Hb increase with task load increase, for 1-back condition.

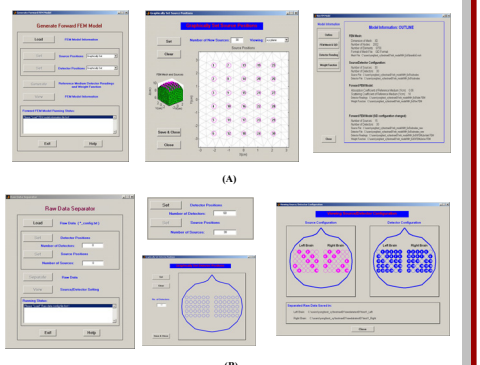

Figure 8. User interfaces for: (A) FEM Model generator; (B) Raw Data Separator.