

REAL-TIME-FUNCTIONAL MRI EXPLORER

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Abstract

In this paper we present a system that allows online-control of functional magnetic resonance imaging (fMRI) experiments. With the beginning of the fMRI experiment, the functional volumes are real-time exported to an external PC. The statistical relevance of each voxel's activation is then calculated by correlation analysis. After calculation, the activation maps are overlaid to an anatomical data set. The real-time visualization of the activated voxels in combination with the morphology gives relevant information to the physician at experiment's run time. The physician can set different levels of significance for activation, can investigate both slice-wise and as a 3d rendered volume, and can take localization measurements in Talairach coordinates.

The system is in use in cooperation with the German Cancer Research Center in Heidelberg and the Otto-Selz-Institute at the University of Mannheim. The aim is to detect activated brain areas during somatosensory stimulation with experimental pain models. The presented system allows monitoring ongoing fMRI experiments in order to optimize experimental design and slice positioning.

Introduction

Functional magnetic resonance imaging (fMRI) is a non-invasive method that allows monitoring neuronal activation to external stimulation. Since the difference between active and non-active regions is about 2-3% of the total MRI-signal, averaging, and in particular, statistical testing are mandatory in order to locate active brain areas. An fMRI measurement can take some tens of minutes, and requires an even longer statistical post-processing of the data. Unsuccessful experiments may often turn out to be unsuccessful after a long delay only, when subjects or patients are no longer available for investigation. Real-time functional MRI allows adaptation of experimental parameters or removal of artifact sources during the same experimental session. Measuring brain activation due to somatosensory and especially painful stimulation requires careful experimental design and slice positioning. Real-time fMRI can be used for a first check of the stimulation design and may also be used to select a reduced set of slices for monitoring specific brain regions with improved time resolution, compared with a whole-brain fMRI acquisition.

The only fMRI-online evaluation program we know is that of the fire-project [1-3]. In contrast to this project we only use a standard PC and a newer rendering library VGL3.1 with our own rendering software.

RT-fMRI-Explorer

The basic idea of the RT-fMRI-Explorer is to support fMRI measurements by online monitoring. In order to realize this, we have chosen the following system design: first, an anatomical data set is acquired and sent to an external PC via TCP/IP. When starting functional measurements, a data collector is started on the host-computer of the MR scanner, which collects the functional data volumes and sends them to the external PC via TCP/IP during ongoing measurements. The software on the external PC performs a sliding-window correlation analysis of the last N incoming functional data volumes with a predefined ideal stimulus function $f(x)$ which indicates the time course of stimulation. Classical fMRI "blocked-designs", where the stimulus is alternately switched on and off, are coded by a sequence of 0 (=OFF) and 1 (=ON). The resulting square wave might be additionally convoluted with an ideal hemodynamic response function (HRF), to provide an ideal estimator for stimulation effects.

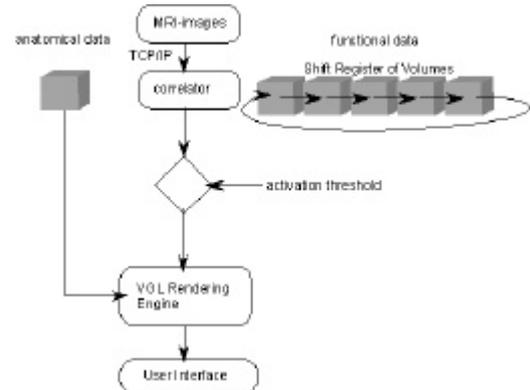


Fig. 1: Internal architecture of the RT-fMRI-Explorer.

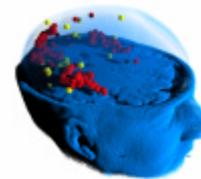


Fig. 2: Volume rendering of the brain in combination with the activated areas in one image (red and yellow).

The sliding window correlation analysis provides a simple functional activity measure for each voxel, which is transformed onto a parametric functional map. Anatomical data and functional maps are rendered together by the VGL rendering engine (using VGL3.1 as rendering library) and then displayed on the screen of the external PC. Talairach coordinates [4] for functional

active locations can be seen by moving the computer mouse cursor to the appropriate position.

The main advantage of our visualization system is the rendering of a "glass" or semi-transparent brain. This allows the user to see both the anatomical structures and the activation area as shown in the following image.

Data Transfer between MRI-System and Explorer

The communication between the MR-system (1.5T Magnetom Vision, Siemens, Erlangen, Germany) and the Explorer is realized by a TCP/IP-interface. This guarantees that no data is lost during transfer. The program itself can be run in two different modes. The real-time receiver mode obtains data from a TCP/IP-connection. In this mode the data is received during the measurement, it is forwarded to the processing routines (correlation), and it is stored for further processing on the local hard disk.

The second mode allows reading data from the hard disk for further processing and visualization, allowing additionally quick off-line investigation of fMRI data sets. In a typical whole-brain fMRI experiment, the data rate normally exceeds the constraints of the MR scanner data base. The data is cached and not written to hard disk until the experiment has finished. In this case no real-time export of the data would be possible. In order to circumvent this problem, data of several slices are stored in one data file (a so called "stamps data file"; Fig. 3) and thus the number of generated files can be considerably reduced. Depending on the measurement sequence and slice count, the data in the stamps might be arranged in various ways. Our software automatically decodes the stamps data back into the correct sequence in the data volume.

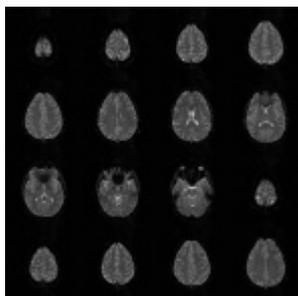


Fig. 3: The slices of one functional volume are stored in "stamps" data files.

User-Interface

The user-interface of the system allows rendering the data two- and three-dimensional (Fig. 4). The two-dimensional images are axis-parallel cuts through the data volume. In order to select their location, a cursor was implemented that visualizes the position of the currently displayed slice cuts.

The three-dimensional rendering is realized by the volume rendering library VGL3.1 by Volume Graphics GmbH. It allows both to combine different volumes, and in addition OpenGL objects (polygons) to be visualized in

interactive time on a normal PC. Both objects can be rotated arbitrarily and the transparency of the gray values can be changed. The user sees a preview of each of the three cuts and the 3d rendered image in four small windows on the left side. Each of these windows might be displayed in the main windows by mouse clicks. Functional maps can be thresholded by moving a slider on the screen, to select voxels above a certain correlation coefficient for display. In order to locate functional activation in a standard anatomical reference system, it is possible to obtain Talairach-coordinates for an area of the volume selected by the PC-mouse.

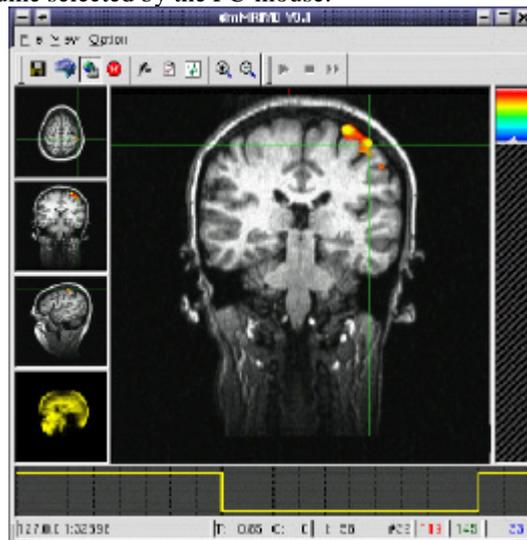


Fig. 4: User-interface. Anatomical data set with overlaid color-coded functional activation map.

Results

The most time critical part of this software is the voxel-wise correlation analysis. We implemented these operations in C++ using a sliding window with a typical width of 20 time steps (=volumes). The computation time for a 128^3 volume therefore takes about 1 second. Since the rate with which the volumes arrive at the system is 4 seconds, this correlation is not time-critical.

Acknowledgment

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References

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