

Whole Brain Real-Time fMRI

RW Cox and A Jesmanowicz

Biophysics Research Institute, Medical College of Wisconsin, Milwaukee WI USA

Introduction: “Real-time” functional MRI allows the investigator to see the brain mapping results during a scanning session. The activation maps can be computed using a recursive formulation of the correlation method—multiple linear regression of the voxel time series against known reference waveforms—which means that up-to-date results can be displayed within 1 s of the data acquisition [1]. We have built a “neuroscientist-friendly” environment for whole brain interactive fMRI. The components of this system are shown below:

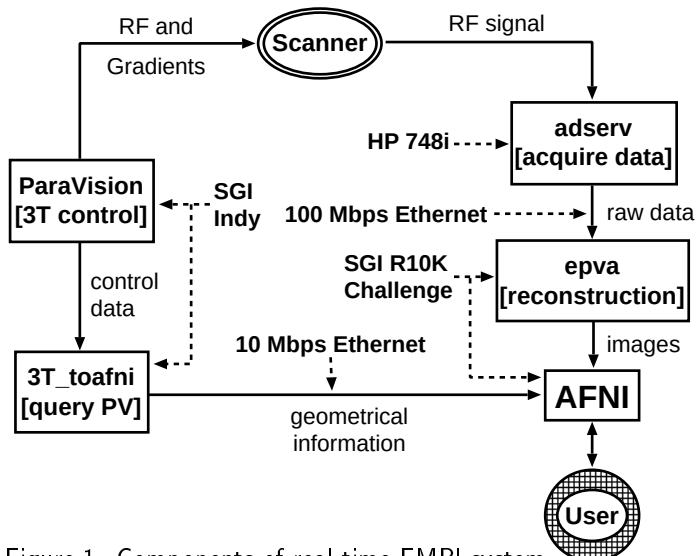


Figure 1. Components of real-time fMRI system.

The Bruker ParaVision software controls the 3T/60 Biospec scanner. The RF signal from the scanner is digitized in an HP-748i VMEbus industrial workstation. The `adserv` software processes the raw k -space data from the A/D cards and sends it over a private network to an SGI R10000 Challenge computer. The `epva` program reconstructs the data (allowing for off-resonance effects and partial k -space trajectories) and transfers the images to the `AFNI` software through shared memory. Since the images carry no geometrical information (e.g., FOV, slice position, thickness, ...), a separate program supplies that information by querying ParaVision.

Speed: The following table shows the acquisitions for which the system outlined above can keep up with real-time. Data are acquired at 10^6 16-bit samples/s for all pulse sequences, and are digitally filtered and subsampled (on the HP-748i) to the desired bandwidth, before being sent to the SGI system for reconstruction. The amount of CPU time spent in the HP system is proportional to the number of raw data points.

Image Matrix	NEX	Raw data points	Time per image (ms)
64×64	1	39 520	100
64×64	$\frac{3}{4}$	29 792	80
128×128	1	78 432	400
128×128	$\frac{1}{2}$	44 384	200

Table 1. Speed of real-time fMRI system.

We note that data is never lost, even if the system falls behind real-time. The software for acquisition of the raw data is written into the Unix kernel on the HP system, and runs as an uninterruptable device driver. All the filtered samples from all acquisitions are stored in memory; `adserv` sends them to `epva` on request. Even if the reconstruction stage falls behind, when the acquisition stops it will eventually catch up. A similar method is used for communication between `epva` and `AFNI`, so that any slowdown in `AFNI` does not affect the reconstruction in `epva`.

More Speed: Time trials using re-played filtered data (so that the acquisition and digital filtering steps are skipped) show that the system can send data across the network, reconstruct the images, and display the functional results at least twice as fast as shown in the table above. During real acquisitions, the uninterruptable acquisition and filtering process is slowing down the data transfer across the network.

Our next step will be to transfer the A/D converters to the SGI system, which has 4 CPUs. In this way, one CPU can be devoted to acquisition, two to reconstruction, and one to functional processing and display. Also, all data transfer will occur using shared memory rather than network protocols. When this is achieved, the system should run about 4 times faster than it does now, and be able to keep up with 10×128^2 full k -space images per second.

Integration with AFNI: As shown in Fig. 1, the reconstructed images are sent directly into the `AFNI` system, a software package for analysis and visualization of fMRI data [2]. To use `AFNI` for real-time fMRI, two external pieces of software are needed: (1) a source of images—2D or 3D, via shared memory or a TCP/IP socket; and (2) a source of geometric and timing information about the images—geometry data can be supplied by the image source, or can be from a separate program. `AFNI` assembles the images as they arrive into a 3D+time dataset, computes the temporal correlation with the ideal response function(s), and displays the results both as montages of slices with color overlays and as time series graphs. This interactive fMRI system contains all the analysis tools of the post-processing system; in fact, there is no distinction between the two analysis environments.

Conclusion: The rapid rise in price/performance of small computers, and the availability of high speed, high precision A/D converters means that real-time image acquisition and reconstruction is becoming inexpensive. Low inductance local gradient coils make it possible to image the entire brain in a few seconds. Combined with `AFNI`, these hardware elements make interactive whole brain neuroscience investigations a reality.

REFERENCES:

1. Cox RW, Jesmanowicz A, and Hyde JS. *Magn. Reson. Med.* **33**:230–236 (1995).
2. Cox RW. *Comput. Biomed. Res.* **29**:162–173 (1996).