Making fMRI More Functional and Reliable

The Signa® MR750 3.0T – Stability for fMRI

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Overview

Functional MRI (fMRI) is a valuable clinical tool for surgical planning and assessing neurological disease and deficits. The basis for fMRI is an increase in blood-flow to the local vasculature that accompanies neural activity in the brain. When the neural activity increases, the local blood flow increases, creating oxygen-rich hemoglobin. This serves as an endogenous contrast mechanism that a T2 or T2* weighted-sequence can detect.

The MR signal associated with changes in blood flow during fMRI is rather small and can easily be masked by noise. For example, at 3.0T, the signal increase associated with brain activity ranges from one-half to four percent above the baseline. Reliably detecting changes this small requires statistical techniques that reduce the impact of spurious noise. Even with statistical processing, distinguishing between activation-induced signal changes and random changes from noise is challenging.

The Signa MR750 system is optimized to minimize system instability and extraneous noise that can negatively impact fMRI and other noise-sensitive techniques. In fact, improving system stability was a primary design parameter that drove the design of the new gradient subsystem and the optical RF receive chain. The result is a 50 percent improvement in overall stability performance over existing systems and enhanced fMRI reliability and functionality for research and clinical applications.

Measuring stability for fMRI

fMRI relies heavily on the image-to-image stability to detect the subtle changes associated with neuronal activity. Therefore, quality assurance metrics derived from the analysis of multi-phase phantom data provide the most pertinent information for fMRI. Although several analysis techniques exist, a widely known method is the Weisskoff analysis.[1] A Weisskoff plot trends the temporal standard deviation of a square region of interest (ROI) as a function of the ROI length and size (Figure 1). In the absence of system imperfections, the noise is uncorrelated and hence, the standard deviations decrease linearly with the ROI size (red line). System instabilities often have a spatial dependence and result in a measured standard deviation that does not trend with the theoretical line.

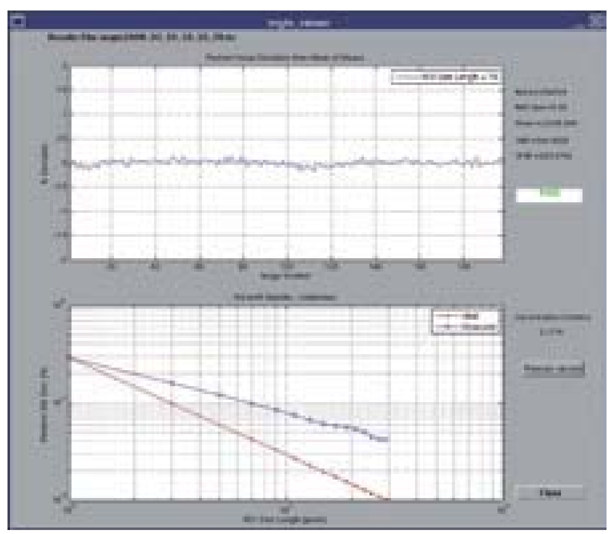

Figure 1. A Weisskoff plot demonstrating the relative standard deviation of the data as a function of the ROI size. System instabilities force the measure stability (blue line) to deviate from the ideal curve (red line).

While Weisskoff plots can be sensitive to system instabilities, this test has limited specificity and is often impacted by the systems signal-to-noise ratio (SNR). For example, the first point (n=1) in plot represents the single point SNR. If the system SNR is low, as represented by a high standard deviation for the first point, system instabilities are masked by too much noise. The result is a plot of measured data that tracks the theoretical line, but in reality provides no useful information about the system stability (Figure 2).

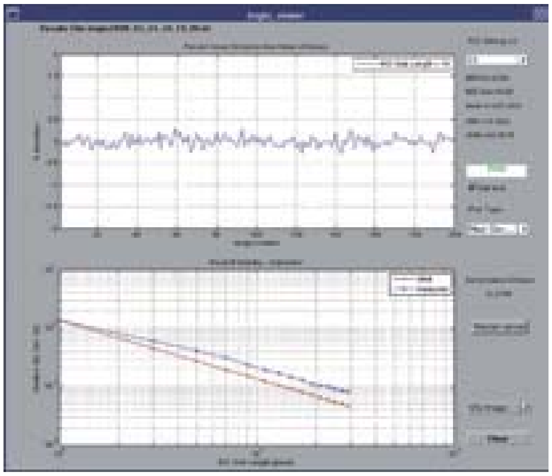

Figure 2. The Weisskoff plot generated by a system exhibiting poor SNR. The measured data follows the theoretical line giving the "false" impression that the system stability is well-behaved.

A less ambiguous approach trends a single metric, such as the relative standard deviation for a particular ROI, over time by performing a daily quality assurance (QA) scan. A routine QA procedure can quickly identify performance changes in system performance, leading to expedited service responses and improved data stability over time.

Signa® MR750 performance levels

Excellent system stability for longitudinal fMRI and quantitative MR examinations is a fundamental design criteria of the Signa MR750 3.0T system. A target level was set at 0.1 percent RMS for the relative deviations across a 19x19 ROI, representing a nearly two-fold improvement over prior MR designs. To demonstrate system stability under extreme conditions, data was acquired and measured from six back-to-back high-duty cycle fMRI scans (protocol: 64x64, 22 cm FOV, 4 mm slice, 1 mm gap, 28 slices, 200 phases, TR=2000, TE=30 ms, quad T/R head coil)* acquired continuously over two hours. As demonstrated in Figure 3, the relative fluctuations are consistently less than the specification with no obvious change over the course of the experiment, demonstrating consistent and reliable results on the Signa MR750.

Figure 3. The measured stability over two hours of continuous scanning using the fMRI stability protocol.

Clinical evaluation

Gary Glover, PhD, Professor of Radiology and Director of the Radiological Sciences Laboratory at Stanford University, has been evaluating the Signa MR750 3.0T MR system for fMRI since its initial installation at his facility in February 2008.

"There are two things that are critical for fMRI performance, and the first is short term stability", says Dr. Glover. "Short term stability means inter-image fluctuation. When I looked at this metric initially at the GE facility, I was pretty impressed that the stability was even better than that of our current 3.0T system, and it was well within the level that I consider essential for fMRI. For fMRI, one wants the system noise to be substantially below that of the physiological noise produced by the brain. Through our own experience and also that of the fBIRN*, we developed a statistic of 0.1 percent RMS fluctuation as an acceptable level. The factory-based prototype system we evaluated was performing at the 0.06 percent level, and with our recently installed system we were able to duplicate that level of stability within the first week in installation."

Dr. Glover continues, "The second important aspect is that the system must keep on performing at that level after continuous scanning. I monitored the image and thermal stability of the system over a 40 minute scan. I stressed the system with my spiral fMRI protocol trying hard to break it, and I was unable to! The gradient temperature equilibrated, while the image stability remained excellent. In summary, the system performance is very strong from my initial experience, and overall I'm pretty enthusiastic."

Conclusion

MR imaging techniques, such as fMRI, that rely on measuring and quantifying subtle physiologic processes place increased demands on the MR system's ability to produce stable results over time. The Signa MR750 supports exceptional system stability to sustain today's research and enable tomorrow's advanced clinical applications. ■

* Note: GE utilizes a protocol promoted by the functional Biomedical Informatics Research Network (fBIRN). For additional information, please see http://www.nbirn.net/index_ie6.shtm.

References

1. Weiskoff, R.M., MRM 36:643-645 (1996). Need citation