

Quadrature slice-encoding for reduced scan time

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Introduction

Conventional MRI methods acquire a set of complex images of brain slices, with each slice individually excited and reconstructed. Except for velocity sensitive applications, the phase of the reconstructed images is discarded due to its lack of clinical significance. Here, we introduce a method that simultaneously excites pairs of adjacent slices and resolves the signal in the slice direction by the phase distribution in each slice, which is collected in a calibration scan. In fMRI, this would double the rate of data acquisition, and allow twice as many temporal frames to be acquired, potentially allowing for improved SNR.

Theory

The method is based on the idea that if two slices are separately excited, the sum of the signals should equal the signal from the slices excited simultaneously. The data is acquired in the frequency domain, but this holds in the image domain also. Thus, we can write $m_L e^{i\phi_L} + m_R e^{i\phi_R} = m_Q e^{i\phi_Q}$, where m and ϕ are magnitude and phase, and the subscripts indicate the slice: L and R are individual slices left and right of the center frequency, and Q is their simultaneous excitation. This gives

$$\begin{bmatrix} m_L \\ m_R \end{bmatrix} = \frac{1}{\sin(\phi_R - \phi_L)} \begin{bmatrix} \sin\phi_R & -\cos\phi_R \\ -\sin\phi_L & \cos\phi_L \end{bmatrix} \begin{bmatrix} m_Q \cos\phi_Q \\ m_Q \sin\phi_Q \end{bmatrix}$$

Conceptually, this method projects a complex signal onto the axes defined by the phases obtained in the calibration. In this method, the slices are excited in quadrature, with phases of $+\pi/4$ and $-\pi/4$. Thus, with no off-resonance between the two slices, the axes should be orthogonal. As the off-resonance increases, however, the inversion becomes less reliable in the presence of noise. The inversion undoubtedly fails when ϕ_L and ϕ_R are $\pi/2$ out of phase. The off-resonance to produce a phase shift of $\Delta\phi$ with an echo time TE is given by $\Delta f = \Delta\phi/(2\pi TE)$. Thus, with $\Delta\phi = \pi/2$ and $TE = 30\text{ms}$, an off-resonance of $\Delta f = 8\text{ Hz}$ will breakdown the inversion. In uniform brain regions, however, the field homogeneity across adjacent pixels is within this limit, and the method should theoretically work.

Another practical issue for this method present in many MRI scanners is phase-drift. Because the inversion requires a constant relative phase between the calibration and functional scans, phase-drift may impair the reconstruction. To correct for this, the calibration scan alternates between the RF pulses for the L , R , and Q slices for multiple temporal frames to approximate the phase drift and remove it, and then averages. This gives the correct phase relationship between the L , R , and Q slices. During the functional scan, a low-order polynomial is removed from the time series, and the phase is offset to match the mean phase of the Q slice from the calibration.

Methods

Images were acquired on a 3T GE scanner using a spiral in-out pulse sequence ($TR/TE = 1000/30\text{ms}$, slice-thickness = 4mm, FOV = 22cm, matrix size = 64x64). The subject underwent a 30s calibration scan followed by a functional scan. For the current preliminary study, no time-course analysis was performed.

Results and Discussion

Figure 1 shows the raw data collected from the calibration and functional scans, and Figure 2 shows the resulting reconstructed slices. As seen in Figure 2, the reconstruction in most regions of the brain is accurate. However, in regions near large magnetic susceptibilities, such as in the frontal brain regions, phase shifts from off-resonance render the reconstruction unreliable, as seen from the percent error maps. In addition, due to the large phase variation in these regions, the reconstruction is more sensitive to small head motion. Furthermore, because two slices are excited, the effect of signal dropout in these regions is greater, as seen by the decreased magnitude in the frontal brain region of the quadrature image (see Figure 1).

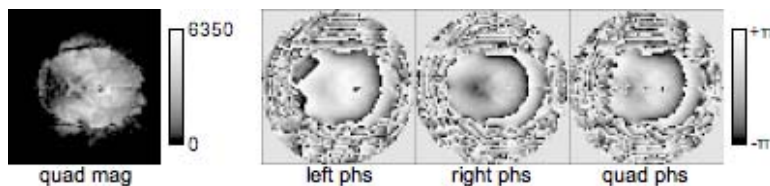


Figure 1: Raw data from calibration and quadrature scans

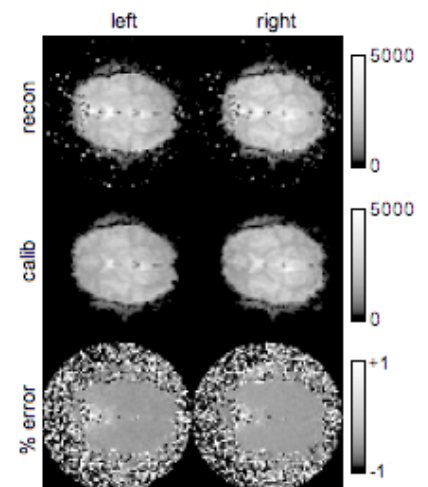


Figure 2: Reconstruction and % error

Conclusions

The introduced method is shown to work in uniform brain regions and may lead to greater SNR due to more measurements. However, the reconstruction is inaccurate in regions near large magnetic susceptibilities. To optimize this method, the effects of slice thickness and echo time on reconstruction accuracy need to be investigated. Furthermore, the improvements in the reconstruction by extending of this method to multiple slices (>2), thereby giving more measurements per TR, need to be studied. After optimizing the method based on these considerations, we will perform functional scans to assess the potential SNR gain relative to a conventional spiral fMRI sequence.