RF excitation encoding: a fast imaging technique for dynamic studies

Y. Hu[1]**, and G. H. Glover**[2]
[1]Imaging Research Center, University of Texas at Austin, Austin, TX, United States, [2]Department of Radiology, Stanford University, Stanford, CA, United States

Introduction: For dynamic studies such as functional MRI (fMRI), to achieve reasonable temporal resolution, spatial resolution and spatial coverage, it is necessary to use an under-sampling technique to speed up data acquisition. There are two effective ways to remove aliasing artifacts associated with under-sampling. One is parallel imaging (1, 2) and the other is the UNFOLD technique (3). Parallel imaging utilizes non-redundant sensitivity information provided by multi-channel coils to obtain alias-free images, whereas the UNFOLD technique utilizes temporal frequency information to filter out aliasing artifacts. Both approaches attack the problem from the acquisition side. They can be combined to enhance the effectiveness in removing aliasing artifacts (4). However, if we try to combine them to achieve a higher reduction factor, significant complication can be observed. In this work, a new technique called RF excitation encoding (REE) will be introduced. It approaches the problem from the excitation side. Slices will first be grouped into clusters with each cluster containing the same number of slices. For each time frame, clusters are excited with unique combinations of all slices. The excitation pulse is selected from a pool of RF pulses and looped through the pool repeatedly. The pool of RF pulses is designed so that each slice in the cluster corresponds to a specific frequency in the spectrum of temporal signal at any give k-space location. Then k-space signal for each slice can be easily separated by using an appropriate filter. Since slices in each cluster are excited together for each time frame, the volume TR can be reduced by a factor which equals the number of slices in each cluster.

Methods: Assume that the number of slices in each cluster is N_c. To ensure each slice corresponds to a specific frequency in the spectrum, appropriate phase has to be added to each slice in each excitation pulse. The size of the pool of RF pulses is N_c, and the RF pulses in the pool can be expressed as

$$B_{1,m}(t) = \sum_n B_1(t) \cdot S((n-1)z_0, t) \cdot e^{i \cdot (m-1)(n-1) \cdot 2\pi / N_c} ,$$

where $B_{1,m}$ is the mth excitation pulse in the pool, B_1 is the RF pulse, *e.g.* a simple sinc pulse, to excite a single slice (without phase addition it excites the first slice in the cluster), z_0 is the slice thickness, $S((n-1)z_0, t)$ is the phase addition to B_1 to shift the location of the excited slice so that nth slice in the cluster is targeted. Each pulse excites all slices in the cluster. When RF pulses in the pool are looped repeatedly, there will be N_c peaks in the spectrum of signal at any given k-space point. If we scan the spectrum from the center towards the right and wrap around to the leftmost once it reaches the rightmost frequency component, then the first peak we see corresponds to the first slice, the second peak corresponds to the second slice and so on. K-space signal from a specific slice can be obtained by filtering out spectral peaks corresponding to all other slices. In this work, the REE technique is demonstrated with $N_c=2$. There are two excitation pulses in the pool. One excites two adjacent slices in phase and the other excites two slices out of phase. Then the spectral peak at the center comes from k-space signal in the first slice and the spectral peak at the Nyquist corresponds to signal in the second slice. By zeroing out 5 frequency components centered at the unwanted spectral peak, k-space signal from the two slices can be separated. A reference image can also be obtained from the same set of data. Two adjacent time frames can be combined to separate k-space signal for each slice with the use of linear algebra. The volume TR will be doubled in this case. To test the performance of the REE technique, a dynamic study was performed on a normal volunteer using our 3T MR scanner (GEMS, Milwaukee, WI, USA). The spiral sequence (5) is used to acquire k-space data. 10 3mm slices are collected with a TR of 1s and TE of 30ms. FOV is 22cm and matrix size is 96×96. Altogether 200 time frames are collected.

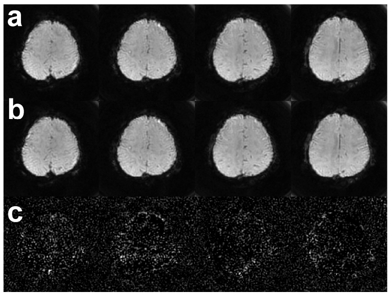

Figure 1. Reference images (20th out of 100), REE images (40th out of 200) and difference images (×20) are shown in a, b and c respectively. Here 1 reference image corresponds to two REE images.

Results: Reference images as described in the Methods section, images reconstructed by the REE technique and difference images (×20) are shown in Figure 1a, 1b and 1c respectively. We can see that the REE technique was effective in separating signal from different slices. Since temporal SNR (tSNR) is very important to dynamic studies, a comparison of tSNR is provided in Figure 2 with 2a for reference images and 2b for REE images. Since reference images are obtained by combing two adjacent time frames, its tSNR is $\sqrt{2}$ larger by theory. In Figure 2a, the tSNR is scaled by $1/\sqrt{2}$ so that it can be compared with that of REE images directly using the same display range. It can be easily seen that the tSNR performance the REE technique (Fig. 2b) is quite close to its theoretical prediction (Fig. 2a).

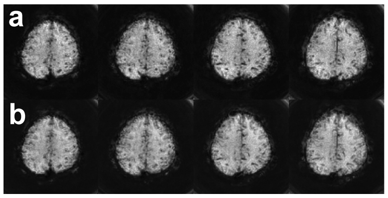

Figure 2. tSNR of reference images (×0.707) and REE images are shown in a and b respectively.

Discussion: Under-sampling in the acquisition side has been widely exploited to speed up image acquisition. However, less effort, to our best knowledge, has been involved in fast imaging from the excitation side. Although parallel excitation attacks the problem from the excitation side, it is mainly targeted to reduce the long excitation pulse in applications where spatial selection is needed in multiple dimensions. The REE technique intends to work with the normal slice selective RF pulses to accelerate image acquisition for typical dynamic studies. Since it is focused on the excitation side, it can be safely combined with speed-up techniques focused on the acquisition side to achieve higher reduction factor. The signal modulation introduced by the REE technique is independent of under-sampled k-space trajectories and therefore won't cause significant complication to methods focused on the acquisition side. Like all other fast imaging techniques, the REE technique has to trade SNR for speed. Since all slices in a cluster are excited together for every time frame, spins have less time to relax (by a factor of N_c) and thus have a lower steady state signal. However, there is no loss in statistic analysis power because more time frames are acquired given the same amount of scan time. This work gives an introduction to the REE technique. In the future, we plan to implement its use for high-resolution fMRI studies to improve temporal resolution, and to explore the possibility of combining the REE technique with parallel imaging to further accelerate image acquisition for dynamic studies.

References:

1. Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P. Magn Reson Med 1999;42(5):952-962.
2. Griswold MA, Jakob PM, Heidemann RM, et al. Magn Reson Med 2002; 47: 1202-1210.
3. Madore B, Glover GH, Pelc NJ. Magn Reson Med 1999;42(5):813-828.
4. Madore B, Magn Reson Med 2002;48(3):493-501.
5. Glover, GH. Magn Reson Med 1999;42(2):412-415.