Hilbert-Sampling in k-Space

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Introduction Acoustic noise generated by pulsed gradients is one of the main annoyances in MRI. Especially in fMRI this noise acts as a distraction that compromises study results by attention effects. In auditory processing fMRI experiments, the influence of scanner acoustic noise is even more direct and stronger. Additionally a cross-modal interaction has been shown [1] where acoustic noise influences cortical areas responsible for primary visual processing.

Methods In standard EPI, the k-space is traversed in a line-by-line fashion. This sampling scheme implies a long constant gradient plateau during the line traversal and a large change in gradient amplitude in the transition between two successive lines. These rare (compared to the sampling rate) changes in gradient amplitude with high magnitude lead to the typical acoustic noise generated by EPI sequences. In our approach, k-space is traversed along an iteration of the Hilbert-Moore (HM) curve [2]. The more frequent gradient switching needed to realize the sampling of k-space along the Hilbert-Moore curve leads to a more favorable sound profile of the resulting acoustic noise. To acquire an image with 64x64 resolution, k-space is sampled along a 32x32 curve with two-fold oversampling, and interpolation of the missing values (Fig.1).

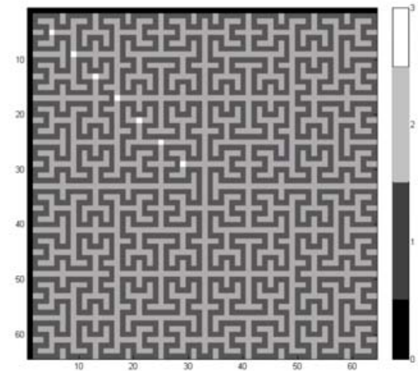

Figure 1: Hilbert-Moore curve
1: Direct acquisition. 2: pair-wise interpolation, 3 two-fold interpolation

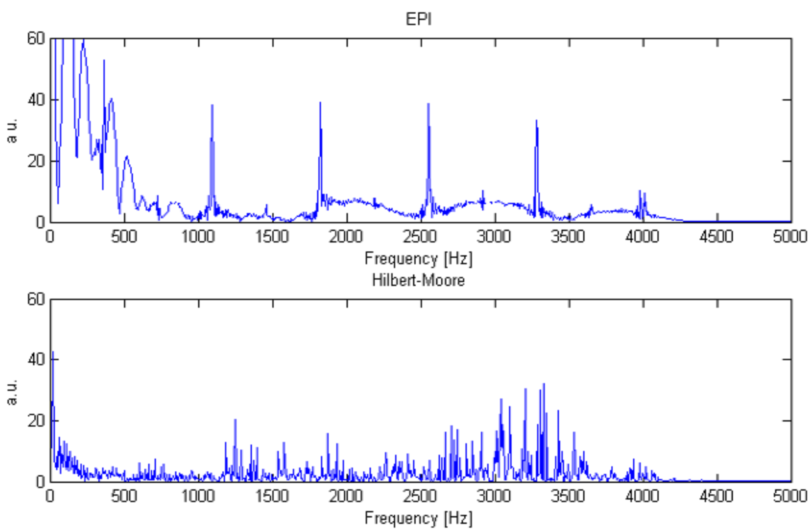

Figure 2: Frequency-analysis of EPI and HM acoustic noise

Results Here the HM sequence and an EPI product sequence are evaluated with respect to sound characteristics and image quality. Comparing the sound spectra, the spectrum of the EPI sequence (Fig.2 top) reveals few elevated frequencies with high amplitudes - a generic feature of EPI sequences. The HM sequence, in contrast, shows a broader frequency distribution and no single frequencies are elevated (Fig.2 bottom). The image quality can be judged from Fig. 3 and 4 that show images with 64x64 matrix size of a phantom consisting of two bottles filled with tap water. Measurements were performed on a Siemens Tim TRIO 3T scanner equipped with a standard head coil. The shape of the objects is more realistically depicted by the HM sequence. The EPI image was reconstructed on the scanner, the HM image externally using MATLAB (the Mathworks Inc.). Furthermore, successful fMRI BOLD measurements using stimulation of the Visual Cortex have been performed.

Discussion The presented results show the potential of the HM k-space trajectories. In addition to the advantageous sound profile, it allows a free choice of the echo time, because it is possible to start sampling at an arbitrary point of the HM curve. However, the approach is currently limited by the time needed to acquire one image slice. Using a FOV of 400mm, and an imaging matrix of 64x64 pixels, the time to acquire one slice with HM is 60ms, which is significantly larger than the minimally possible acquisition time of an EPI sequence. This increase in acquisition time is due to hardware limits like the gradient raster time and the gradient slew rate. The gradient raster time restricts the gradient switching to one possible step every 10µs. Furthermore the gradient slew rate is the time limiting factor for one blip, which is used to move one step in k-space. A significant reduction of measurement time would be possible using more powerful gradient hardware or parallel imaging techniques.

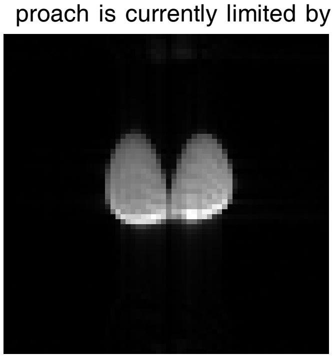

Figure 3: EPI Image
FOV 400mm, 64x64, TR 142ms, TE 53ms, 752Hz/Px

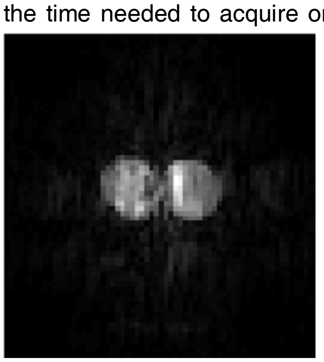

Figure 4: Hilbert-Moore Image
FOV 400mm, 64x64, TR 65,2ms, TE 53.7ms

References [1] N.Zhang, X.-H.Zhu, and W.Chen, *Magn.Reson.Med.*, 54(2):258–259, 2005 [2] Sagan, H. *Space Filling Curves*, Springer Verlag,1994