Continuous Cartesian Sampling: A Simple Method to Improve Image SNR

C. A. Bookwalter[1], J. L. Duerk[1,2]
[1]Case Western Reserve University, Cleveland, OH, United States, [2]University Hospitals Cleveland, Cleveland, OH, United States

Introduction: Echo-planar and spiral MRI pulse sequences are known for their short acquisition times and artifacts associated with the sampling trajectory, shared similarities resulting from signal sampling during the entire gradient application. By sampling continuously, these methods have no “dead time” in which no data is collected. Although the advantages of continuous sampling are clear, this concept has not been extended to ordinary rectilinear or radial MRI sequences. Specifically, rectilinear data is traditionally collected only during the flat top portion of the readout lobe of the frequency encoding gradient waveforms. This results in uniformly sampled k-space data, which is easily transformed to image space with a 2DFT. Unfortunately, more than half the time between consecutive excitations is often not utilized for signal detection, even though the MR signal is always frequency encoded to some location in k-space. In this study, an ordinary rectilinear FLASH pulse sequence was modified to sample data continuously following slice refocusing to obtain a potential SNR gain without increasing imaging time. This method only required a switch from a simple 2DFT to a nearest neighbor gridding reconstruction prior to 2DFT.

Methods: A standard rectilinear FLASH pulse sequence was modified to achieve a continuously sampled rectilinear pulse sequence using standard pulse sequence tools (e.g., ICE, IDEA) on a 1.5T Siemens Sonata system. The minimum TR of an ordinary FLASH sequence was increased from 9.1 ms to 14 ms to prevent overlapping of gradients in order to accommodate the continuous sampling method. The total sampling time of the sequence was increased from 2.56 ms to 7.04 ms. A partial pulse sequence diagram showing traditional sampling (solid ADC) and continuous sampling (dashed ADC) is shown in Figure 1a. The traditional path through k-space for one repetition time corresponds to arrow 2 in Figure 1b. The newly developed pulse sequence takes advantage of the traditionally unsampled path (arrow 1 - dephase lobe, arrow 2a and 2b - ramp for readout lobe, and arrow 3 - rephase lobe in Figure 1b) through k-space. The continuous sampling sequence samples every k-space pixel at least twice, once during the readout lobe and once during the rephase or dephase lobe.

Nearest neighbor gridding of the data (assuming an ideal trajectory) to an oversized rectilinear matrix was used for reconstruction. All data points mapped to the same pixel in k-space were averaged. The gridding method was used to either reconstruct all the data together or to reconstruct each gradient lobe data separately. When the gradient lobe data was regridded separately, homodyne detection [1,2] was used to reconstruct the partial k-space data from the dephase and rephase lobes. After gridding and homodyne detection, the three gradient lobe data sets were magnitude reconstructed and averaged in the image domain to generate a final image. Images from a standard resolution phantom and a healthy human volunteer were collected. Imaging parameters used were TE = 7 ms, TR = 14 ms, FOV = 300, slice thickness = 5mm.

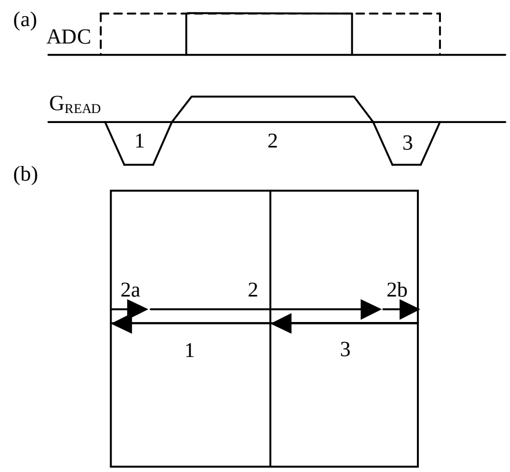

Figure 1: Partial pulse sequence diagram (a) showing continuous sampling (dashed line) and traditional sampling (solid line) and k-space trajectory (b) with arrows corresponding to gradient lobes shown in (a).

Results: A traditionally sampled image (i.e., data sampled during the constant portion of the readout lobe of the frequency encoding gradient) is shown in Figure 2a and 3a. Figure 2b and 3b show a continuously sampled image with all data reconstructed together. Some shading and ringing artifacts are seen in Figure 2b and 3b. The initial results show increased SNR by about 30% (SNR = 118 for continuous sampling and 90 for traditional sampling in phantom images) even for simple gridding of the entire data set to a rectilinear grid. The increase in SNR is slightly higher with the homodyne detection, but artifacts are more visible.

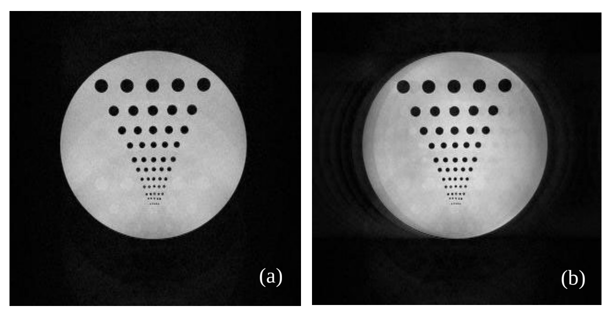

Figure 2: Traditional FLASH images of phantom (a) and continuous sampling image (b) reconstructed by gridding to a rectilinear matrix.

Discussion: This work successfully demonstrates the ability of continuous sampling to increase SNR of a rectilinear FLASH sequence. The method is easily extended to any other pulse sequence. Ideally, SNR would increase by a factor of $\sqrt{2}$ because our data consisted of at least two points per pixel. Although TR was increased to accommodate non-overlapping gradients (e.g., slice and spatial encoding) necessary for continuous sampling, TR may increase less when continuous sampling is implemented in radial sequences where gradient overlap would be desirable. Shading artifacts in the images may be due to phase correction failure in the half Fourier reconstruction or due to phase averaging in the simple gridding reconstruction. Compensation for off-resonance effects with methods such as multifrequency interpolation [3] may reduce such artifacts. In addition to the gain in SNR, other uses may be found for this “extra” data.

Conclusion: This surprisingly simple technique leads to a theoretical gain in SNR of $\sqrt{2}$ and in our experience, an actual gain of about 30%. This method could be applied to virtually any conventional rectilinear pulse sequence to boost SNR without a significant increase in imaging time or computation time.

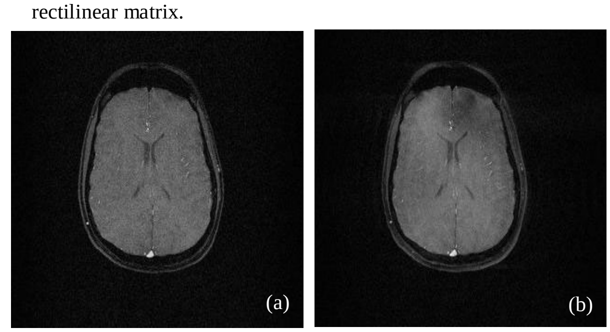

Figure 3: Healthy volunteer *in vivo* FLASH images using traditional sampling (a) and using continuous sampling (b).

References: [1] Noll et.al., IEEE TMI, 10, 154-163, 1991. [2] McGibney et.al., MRM, 30, 51-59, 1993. [3] Man et.al., MRM, 37, 785-792, 1997.