Self Rewinding Trajectories for Spectroscopic Imaging

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Introduction:

An extensive analysis [1] compared a number of fast Chemical Shift Imaging (CSI) methods to the gold standard Cartesian CSI and found that while they provided a speed up in data acquisition, the sensitivity of the experiment (defined as the ratio of the SNR to the square root of the total acquisition time) was generally lower than the one achieved by CSI. Not covered in [1], and of particular interest to us, is a class of CSI methods that uses trajectories self-rewinding to the center of K-space. Members of this class are Out-and-In Spiral CSI and Rosette Spectroscopic Imaging (RSI). We will show that any imaging technique that periodically samples the center of K-space could be used for spectroscopic imaging, providing not only a significant speed up in data acquisition but also potentially a higher sensitivity compared to conventional CSI.

Theory:

As noted in [2], techniques covering a disk rather than a square in *Kx-Ky* space have an intrinsic SNR advantage. In fact, our results show an increase in SNR of $\cong \sqrt{4/\pi}$ for a disk supported CSI *vs.* the square supported CSI acquisitions, which suggest the high-frequency information in the corners of K-space contribute only noise (even if improving diagonal resolution when zero padded reconstruction used). Considering the total acquisition time for the square is higher than the time for the disk by $4/\pi$, the quality factor or the performance of the disk acquisition experiment defined as the ratio of the disk supported CSI sensitivity to the square supported CSI sensitivity is: $\Omega_{diskCSI} = \sqrt{4/\pi}/\sqrt{\pi/4} = 4/\pi \cong 1.27$. This is a compelling reason to look at trajectories that do not spend time covering the corners of K-space. In Fig. 1 self-rewinded trajectories are depicted in K-t space. They start at K=0, extend out to $K = K_{\max}$ and return to K=0 periodically. To avoid temporal aliasing, the maximum bandwidth to be used for reconstruction is the inverse of the time separation between two consecutive samplings of K=0 (interval dT shown in Fig. 1). Requiring each temporal slice (defined by consecutive K=0 samplings) is properly sampled in *Kx-Ky,* will provide proper coverage (Nyquist criterion) for the entire K-t space. Gridded data presents itself as a stack of images collected at different echo times allowing recovery of spectral information. In addition, segmented data can be used to generate a B0-map without other acquisition being necessary.

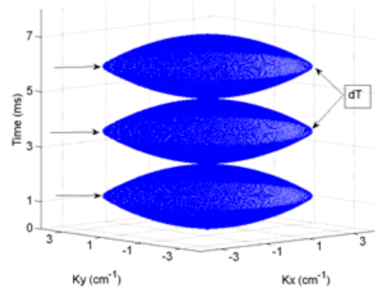

Figure 1: *sTWIRL K-t sampling. Arrows on the left denote the position of the gridding planes.*

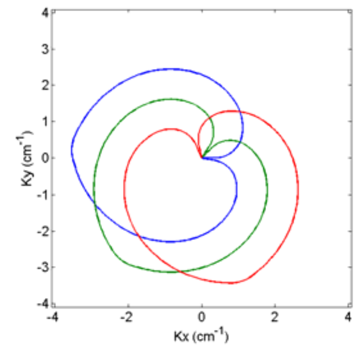

Figure 2: *Pear-like modified TWIRL trajectories.*

While, as mention above, there is a limitation in the bandwidth achievable by these techniques, temporal/spectral interleaves could be used. To double the bandwidth, a second set of trajectories is acquired starting at an echo time $T_{echo} = T_{echo} + (dT/2)$, time-shifted with $dT/2$ in respect to the first set.

TWIRL [3] trajectories consist of four regions: gradient ramp up, rectilinear region extending radially outward, a slew-rate-limited transition region and constant sampling density region. They reach $K = K_{\max}$ with a radial gradient component $G_r = p \cdot G \neq 0$. Because of this, we introduce a fifth region that starts at $K_r < K_{\max}$ determined by:

$$K_{\max} - K_r = G^2 \cdot p^2 \cdot K_{\max}^2 / (2 \cdot K_r^2 \cdot S_d)$$

The gradient radial component is decreased linearly at a constant rate S_d while at the same time G_ϑ is increased such the magnitude of the gradient remains as close as possible to constant G, without violating the scanner maximum slew-rate.

The readout for one segment (from $K = 0$ to $K = K_{\max}$) is slightly different but close to the value quoted in [3]:

$T_r \approx (1-p^2) \cdot K_{\max} / (2pG)$ resulting in a spectral bandwidth $BW = 1/(2 \cdot T_r) \approx pG/(1-p^2)/K_{\max}$.

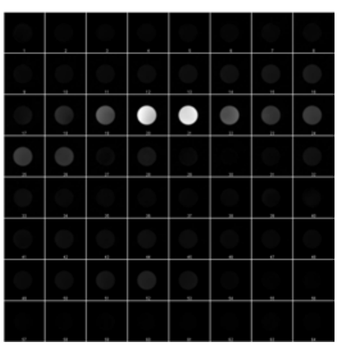

Figure 3: sTWIRL: *Spectroscopic Image of a multiple- peaks vegetable oil phantom. A self-derived B0 map correction was applied.*

Methods:

The spectroscopic imaging trajectory is obtained by concatenating the waveform described above to a waveform that was mirrored with respect to the radial line passing through the point where first segment reaches $K = K_{\max}$. The ramp up region for the second and subsequent waveforms was changed into a constant gradient region , and only the last segment uses a ramp down region such the trajectories finish at G=0 and K=0. After concatenating two segments, one can choose to form figure-eight trajectories or keep rotating the trajectory in a counter-clockwise direction (our choice). Three individual shots within a temporal slice are shown in Fig. 2.

Results:

Experiments were carried out on a whole body 3Tesla General Electric scanner ($S_{\max}$ =15000G/cm/s, $G_{\max}$ =4G/cm)**.** A spectroscopic image of a multiple-peaks vegetable oil bottle was obtained with the spectroscopic TWIRL trajectories. A self-derived B0 map obtained from the collected data was applied to correct for field inhomogeneities (Fig 3).

Conclusions:

Self Rewinding Trajectories that periodically sample the center and edges of K-space are ideal candidates for spectroscopic imaging. A SNR gain over the same acquisition time with respect to standard CSI is achievable or, when the SNR of the experiment is not a concern, a speedup of an order of magnitude in data acquisition is possible.

References: [1] Pohmann et al., JMR, **129**, 145, '97. [2] Bernstein et al., JMRI, **14**, 270, '01. [3] Jackson et al., MRM, **25**, 128, '92.[4] Star-Lack., MRM, **41**, 664, '99.