Precompensation of Spiral Trajectory for Reduced Temporal Fluctuation Noise in fMRI

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Introduction. Image quality in functional magnetic resonance imaging (fMRI) depends heavily on fidelity of the imaging trajectory actually used. Even a calibrated scanner will introduce deviation into a carefully designed trajectory. There are a number of error sources: hardware imperfections, thermal noise, susceptibility, and eddy currents are just a few. If trajectory deviates during image acquisition but reconstruction assumes the designed trajectory, aliasing artifacts will occur. Reconstruction artifacts can be reduced by accurate measurement of actual trajectory. (1)-(3) Even so, it becomes undesirable to have actual trajectory deviate from its intended design when it is easily corrected by precompensation. We therefore propose a linear precompensation technique for generating an actual trajectory close to intended design. Image artifacts can be reduced by using this precompensated trajectory.

Methods. Between design and measured trajectories, deviation can be modeled well as a *forward filter* as in convolution eqn.[1]. An inverse filter, that takes measured trajectory as input and generates design trajectory, is found by solving eqn.[2]. From inverse filter and design trajectory we get the precompensated trajectory in eqn.[3]. When this precompensated trajectory is subject to deviation due to the forward filter model, the design trajectory is returned. Thus using the precompensated trajectory as scanner input, the design trajectory is actually generated in k-space. With this improved accuracy, fewer artifacts appear in images.

$k_m = k_d * h_f$ [1], where * denotes convolution, k_m is measured trajectory, k_d is design trajectory, h_f is forward filter introducing deviation.
$k_d = k_m * h_f^{-1}$ [2],
$k_{pc} = k_d * h_f^{-1}$ [3], where k_{pc} is precompensated trajectory such that $k_{pc} * h_f = k_d$

A two-shot spiral trajectory is used to demonstrate this precompensation technique. Ideally, two interleaves occupy complex conjugate locations in k-space. When that is so, then the complex sum of images from each interleaf will have no aliasing. Nine trajectories for each interleaf are measured (1), then the mean for each interleaf computed. Figure 1 shows those nine measurements and the design trajectory of one interleaf; it is evident that the measurement variance is far smaller in comparison to their deviation from design trajectory. The real and imaginary part of each mean trajectory separately replaces k_m in eqn.[1] to calculate a forward filter h_f and an inverse filter h_f^{-1} in eqn.[2]; four forward and four inverse filters in total. Four precompensated trajectories k_{pc} are then calculated. Figure 2 shows design, measured, and precompensated trajectories of one interleaf in a portion of k-space. Notice the deviation of actual measurement from design. Using precompensated trajectory in fMRI, we observed reduction in fluctuation noise caused by motion. Long scan-time in fMRI induces susceptibility to motion artifacts which in turn create noise fluctuations across image time-frames. Twelve oblique brain slices (64X64) were gathered using a quadrature head coil (TR/TE/α /TH/FOV = 1s, 30ms, 70°, 5mm, 20cm) in a GE 3T scanner with scan time of 160s. To emphasize effects of motion, a conventional two-shot experiment (when the two interleaves are acquired within the same TR) was separated into two experiments, each using one interleaf. Therefore, data from each interleaf is gathered with more than 160s elapsed between them. The same subject was scanned using design and precompensated trajectories. After image reconstruction, fluctuation noise is measured by calculating standard deviation across time frames.

Results. To test for reduction in artifacts, a phantom is imaged using precompensated and design trajectories (Figure 3). Artifacts appear as a circular ring at image center; reduced by precompensated trajectory. A series of *in vivo* images are acquired to show how an imperfect trajectory can create more noise fluctuation from motion when compared with a precompensated trajectory. Figure 4 shows temporal standard deviation for each pixel. Notice the decreased fluctuation in these standard-deviation images when precompensated trajectory is used.

Discussion. Even with careful calibration of MRI scanners, actual imaging trajectories will always deviate from their design; in practice, images are typically acquired using imperfect trajectories. We developed a precompensation technique to minimize deviation between design and measured trajectories. We found that image aliasing artifacts from trajectory imperfection are reduced by precompensation. Fluctuation noise caused by motion can also be reduced using our technique.

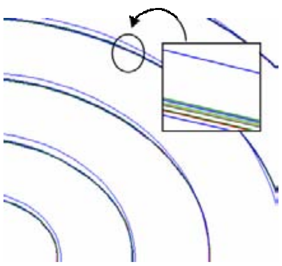

Fig. 1. Nine measured trajectories (bottom in box), and design trajectory above.

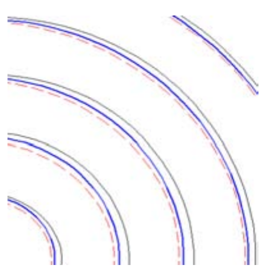

Fig. 2. Design trajectory (thick blue), measured trajectory (dash red), and precompensated trajectory (thin black) used.

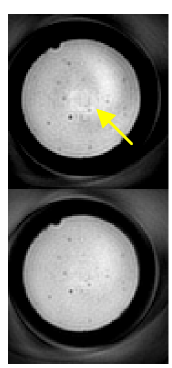

Fig. 3. (left) Artifact from trajectory imperfection using a 2-shot spiral is seen as a ring in image center (arrow). (top) Design trajectory is used but measurement (Fig 1) shows deviation, hence the artifacts. (bottom) Artifacts reduced using pre-compensated trajectory.

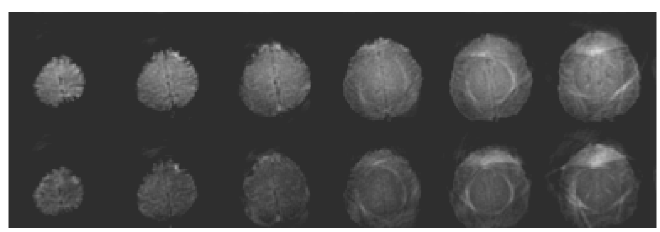

Fig. 4. Standard deviation of image time-frames using (top) design trajectory and (bottom) precompensated trajectory.

Reference. 1. Duyn et al., Magn Reson Med. 1998; 132:150-3. 2. Wansapura et al., Magn Reson Med. 2001; 46:985-992. 3. Alley et al., Magn Reson Med. 1998; 39:581-87.
Supported by NIH RR09784, Lucas Foundation and GEMS.