Motion Compensation Technique using Variable Density Spiral Trajectories

G. Leung[1], D. B. Plewes[1]

[1]Medical Biophysics, Sunnybrook Hospital, Toronto, Ontario, Canada

Introduction: Using a variable density spiral (VDS) trajectory (1,2) that has been shown to be robust in the presence motion, a reconstruction method was developed to further reduce motion artefacts. For this application, the VDS trajectory was designed to adequately sample the same centre region of k-space during each spiral interleave acquisition. These inner, overlapping regions of k-space can then used to measure rigid body motion between each VDS interleave. By applying appropriate phase shifts and rotations of k-space data, the rigid body motion can be removed, resulting in images that have significantly less motion corruption than images without corrections. However, registration accuracy is highly dependent on the pulse sequence parameters. This space was explored to find an optimal design of VDS trajectories for motion compensation.

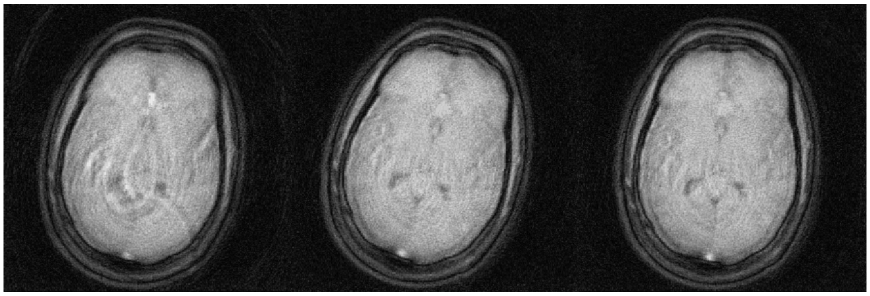
Theory: By rotating one VDS interleave with respect to a reference interleave and regridding, a Cartesian representation of the k-space data is obtained. Subtracting the magnitude data from the overlapping region of each acquisition and repeating for all angles yields a result that will be minimum at the point of maximal rotational correlation between the two k-space acquisitions. To find the rigid body shift, this regridded trajectory is zero padded to 1024 pixels and the maximal correlation between these two trajectories is found using the Fourier correlation theorem. A phase term corresponding to the shift where the two interleaves are maximally correlated is added to the complex data. This modified data is then regridded to the trajectory that has been offset to the correct angle. This strategy removes both rigid rotations and translations from one interleave to the next. To quantify the change in image quality due to modifying the VDS trajectory parameters, the information mean squared error (IMSE) model was used, as a metric that attempts to quantify perceived image quality (3). This measure is calculated as $\mathrm{IMSE} = [A \bullet I(\nabla A) - B \bullet I(\nabla B)]^2$, where ∇ is the two dimensional discrete gradient operator, A and B are the two images being compared, and I is Shannon's measure of information. The closer two images are in quality, the smaller the IMSE between them.

Methods: Images were acquired using the head coil on a standard clinical 1.5 T GE Signa scanner (GE Medical Systems, Milwaukee, WI) equipped with cardiac SR120 gradients. Pulse sequence parameters for the images below were $TR/TE/\theta$ = 80ms/2.5ms/30°, single 5mm slice, 125kHz bandwidth. The variable density spiral trajectory was designed with 3000 readout points, 70 outer interleaves and one single inner interleave over a 20 cm field of view produced images with a spatial resolution of 0.78mm. The inner region produced a centrally regridded region of k-space of 32 × 32 pixels using a Kaiser-Bessel convolution kernel. A volunteer was asked to move their head during the acquisition of data. To explore the optimisation parameter space, a rigid agar phantom was designed to move in the bore of the magnet driven by an ultrasonic stepper motor (MTL Inc Japan**)**. The motion was sinusoidal with a period of .3Hz with rotation of approximately 10 degrees and translation components of 3 cm in both the horizontal and vertical directions. The parameters to be explored were the size of the inner interleave (measured by a variable *ka)*, the length of the spiral readout (*Nr)* and the total number of interleaves *(Ni)*. Trajectories were designed with *ka* ranging from 4 to 20 in increments of 4, *Ni* ranging from 30 to 100 in increments of 10, and *Nr* was selected to give the trajectory a resolution of 0.75 mm. For each of the forty trajectories data was acquired of the phantom in motion and each interleave was registered to a stationary acquisition.

Results: While the VDS trajectory itself removes many of the artefacts of motion, shown below in figure 1a is an acquisition using a VDS trajectory that is corrupted due to motion. Using the same data, figure 1b shows the image after each interleave has been registered to the first interleave. The images have much of the motion artefact due to between interleave motion removed by registering the interleaves before reconstruction. Furthermore, figure 1c shows reconstruction with a different reference in the same data set. Even though the amount of motion is very large, this method is capable of compensating for even large ranges of motion. The results of the optimisation are shown below in figure 2. At low *Ni* for all the trajectories, the IMSE is high, as *Nr* needs to be long to achieve the correct resolution. As *ka* increases, the area available for registration grows with corresponding increases in registration accuracy up to *ka = 8*. Increases in the registration area do not substantially improve image quality beyond this value. However, images become degraded as *Nr* needs to large to achieve the correct resolution. Thus an optimum trajectory with *Ni*=70, *Nr =2188* and *ka* = 8 which corresponds to a radius of 20 pixels in k-space.

Discussion: While a similar technique has been applied in Cartesian sampling (4), the oscilliatory nature of the VDS gradients make it very much less susceptible to intra-scan motion. While the oversampling of the centre of k-space comes at the cost of an increase in the overall scan time, the data averaging produced using this technique further suppresses motion artefacts and yields an increased SNR. While the parameter optimisation is sensitive to both the object being imaged and the nature of the motion itself, this analysis indicates that increasing the registration area to greater than 20 x 20 does not greatly improve registration accuracy. However image quality is degraded due to long readouts. Furthermore, increasing *Ni* increases the averaging of the centre of k-space further reducing motion artefacts. Even in the presence of very large motions this method of motion compensation is capable of generating images that are free from the effects of motion.

References: (**1**) Liao 1997 37(4):569-75 (**2**) Spielman MRM 1995 34(3):388-94 (**3**) Tompa Proc ICIP 2000:489-92 **(4)** Pipe MRM 1999 42(5): 963-9



(a) (b) (c)

Figure 1: Image (a) is corrupted by gross motion artefacts between VDS interleaves, however when first corrected (b), these artefacts are greatly suppresed. To show the amount of motion causing the artefacts in (a), (c) shows the reconstruction technique selecting a different reference interleave from the same data set.

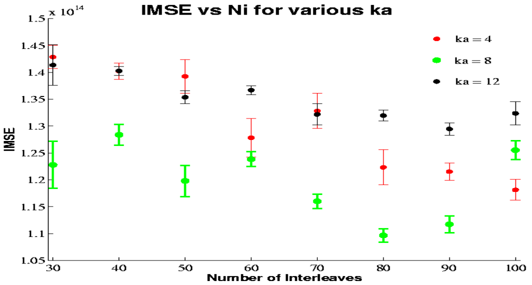


Figure 2: Plot of IMSE vs *Ni* along with standard error for selected trajectories of *ka*. Increasing above *ka=8* begins decreasing image quality due to long readout lengths whereas *ka*< 8 yields poor registrational accuracy also leading to degraded images.