Rigid Body Motion Detection with Lissajous Navigator Echoes

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Introduction

Spherical navigator echoes have been used successfully as a means of estimating rotation in MRI [1]. The spherical navigator covers a sphere in k-space in approximately 20 ms. Its spiral trajectory does however suffer from one shortcoming. As the trajectory nears the pole the slewrate of the gradient waveform increases rapidly. Due to this limit the Spherical navigator is not able to cover the whole spherical surface, but instead leaves the pole caps of the sphere unsampled. Since the rotation estimation relies on the registration of magnitude patterns, errors occur when features rotate out of the sampled area. Thus, for rotations perpendicular to the windings of the spiral (cross thread) a reduced accuracy compared to rotations along the windings has been reported [1]. Here we present an alternative sampling scheme for the spherical surface which is able to sample the complete surface while staying within the slewrate limits of the hardware.

Method

The k-space trajectory of the Lissajous navigator is given by the following formulas, where t ranges from 0 to 2π and $\theta_{periods}$ and $\Phi_{periods}$ are integers.

$$k_x(t) = krad \cdot \sin(\theta_{periods} \cdot t) \cdot \cos(\phi_{periods} \cdot t)$$
$$k_y(t) = krad \cdot \sin(\theta_{periods} \cdot t) \cdot \sin(\phi_{periods} \cdot t)$$
$$k_x(t) = krad \cdot \cos(\theta_{periods} \cdot t)$$

To compare the spherical navigator with the Lissajous navigator, both navigator acquisition schemes have been simulated with the numerical MRI Simulator JEMRIS [2]. The simulations where matched for k-space radius, maximum slewrate, acquisition time and the number of sampling points. The simulated sequence consisted of a 90 degree RF-pulse immediately followed by the navigator acquisition. The object is a three dimensional ellipsoid with semi-axis lengths of 1, 2, and 3 and constant spin density. Rotational motion was simulated by rotating the gradient shapes and keeping the object constant. Relative rotations between 0 and 20 degrees have been applied around each of the principal axis. Rotation was estimated for each axis by comparing all rotated navigators to a reference navigator. Trial rotations are applied to the second navigator and the signal is interpolated by using a convolution gridding on the spherical surface with a Gaussian kernel. The sum of squared differences of the reference navigator signal and the second navigator is minimized using a quasi-Newton line search. The width of the Gaussian is optimized for each navigator separately. All calculations have been carried out using Matlab.

Result & Discussion

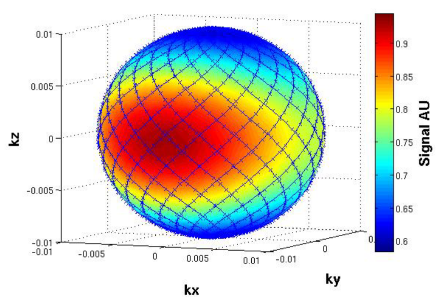

Figure 1: Simulated signal of the Lissajous navigator overlaid by its sampling scheme

Figures 1 and 2 show the simulated signal of the Lissajous and the spherical navigator overlaid by the navigators k-space trajectory. In figure 3 the error of the rotation estimate is shown as a function of the rotation angle for all three principal axis. The spherical navigator performs well as long as the main object features stay inside of the sampled area, which is why it performs well for two axis of rotation. However when it is rotated along the x-axis and the main k-space feature is outside of its sampled area the error of the rotation estimate increases significantly. It's accuracy is thus highly anisotropic. The mean absolute error for the spherical navigator is 0.1 degrees. The accuracy of the Lissajous navigator on the other hand shows less orientation dependency with the rotation estimate error behaving similarly for all three axis while the mean absolute error is comparable to the spherical navigator with 0.15 degrees. The error in the accuracy of the rotation estimate of the spherical navigator drops significantly if a main k-space feature is located at it's pole. While, no matter which orientation, it will be sampled by the Lissajous navigator. For applications such as neuroimaging – where rotation can occur along any axis – this might prove an advantage.

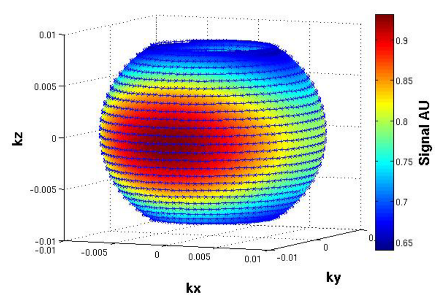

Figure 2: Simulated signal of the spherical navigator overlaid by its sampling scheme

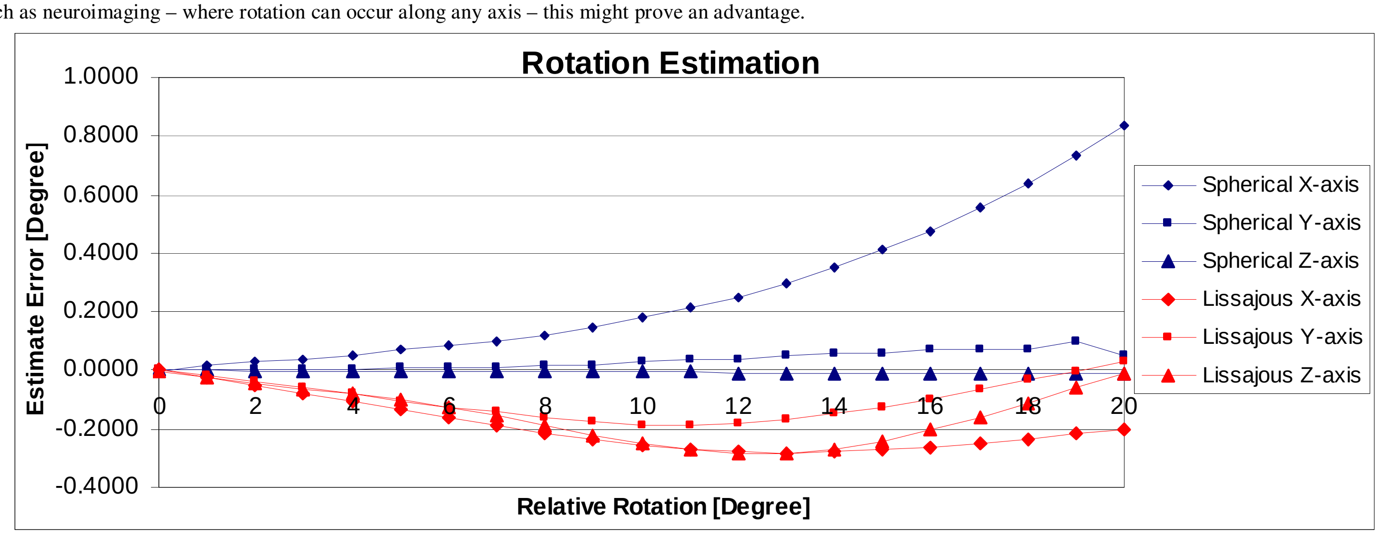

Figure 3: Rotation estimation error as a function of the relative rotation angle between navigator and reference navigator.

1. Welch EB, Manduca A, Grimm RC, Ward HA, Clifford RJ, Magn Reson Med. 2002; 47(1):32-41
2. JEMRIS: www.jemris.org