Diffusion Spectrum Imaging Using Body-Center-Cubic Sampling Scheme

W-Y. Chiang[1], V. J. Wedeen[2], L-W. Kuo[3], M-H. Perng[1], W-Y. I. Tseng[4]

[1]Precision Positioning and Control Lab, Department of Power Mechanical Engineering, National Tsing Hua University, Hsinchu, Taiwan, [2]MGH Martinos Center for Biomedical Imaging, Harvard Medical School, Charlestown, MA, United States, [3]Interdisciplinary MRI/MRS Lab, Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan, [4]Center for Optoelectronic Biomedicine, National Taiwan University College of Medicine, Taipei, Taiwan

Abstract

In order to shorten the data acquisition time of diffusion spectrum imaging (DSI) [1], a new homogeneous sampling scheme in q-space is proposed that the body-center cubic (BCC) sampling lattice, which was previously experimented in CT or MRI [2], is used instead of the Cartesian one. For spherical band-limited 3D signal, BCC sampling lattice is one of the most efficient sampling schemes, and the sampling efficiency of BCC is 30% higher than the conventional Cartesian one [2]. Because there are similar features in the diffusion spectrum of DSI, using BCC sampling scheme may reduce sampling number up to 30% theoretically, which means 30% reduction of data acquisition time. Once the q-space data of BCC lattice is acquired, probability density function (PDF) is reconstructed directly by BCC inverse discrete Fourier transform (IDFT) without interpolation. In addition, BCC sampling method saves data storage volume for 30% as well.

Introduction

Although fiber crossing problem was solved by DSI [1,3], the data acquisition time of it is too long (compared with DTI) and making it unacceptable in clinical setting. For instance, the optimum condition for clinical DSI is set to be 515 diffusion-encoding gradients and b_{max} = 6000 s/mm^2 [4], and this requires data acquisition time up to more than one hour. Traditionally, data acquisition time is saved by reducing the sampling number in q-space, but reduced number of sampling data may introduce aliasing effect, loss of PDF detail, and SNR drop, etc. These problems may result in errors in fiber orientations.

When BCC sampling lattice in q-space is used, the aliasing effect of PDF can be reduced because the repeated patterns is shifted to the corner of FOV (field of view) (Fig.2), and the detail of PDF may be preserved by its higher sampling efficiency (Fig.1). Therefore, if spherical windowing function is used, the aliased pattern of PDF in the corner of FOV can be totally removed whereas the aliased signal in the Cartesian one still remains (Fig.2).

Materials and Methods

DSI data were obtained from one healthy volunteer with a 3T MRI system (Trio, Siemens, Erlangen, Germany). A twice-refocused balanced echo diffusion EPI sequence was used to acquire MR diffusion images which were acquired with 515 diffusion-encodings comprising isotropic 3D grid points over the q-space. DSI data were acquired with b_{max} = 6000 s/mm^2, and TR/TE = 2900/150 ms, and isotropic voxels were obtained by setting in-plane resolution and slice thickness to be 2.7 mm. 40 horizontal slices encompassing the middle portion of the brain were acquired. Data of 515 points sampled by Cartesian lattice in q-space served as the gold standard. Two sets of reduced number of sampling points with different sampling lattice, i.e. BCC and Cartesian, were assigned to be Set1 (experimental set) and Set2 (control set), respectively. The number of data points between Set1 and Set2 was set as close as possible. The DSI data with reduced sampling number of the Set1 and Set2 were obtained by sub-sampling / interpolation from the same gold standard. The data points of all the experiment sets stated above were sampled within sphere of radius of b_{max} equals 6000 s/mm^2. Hamming filter was performed before reconstructions of PDFs for all experiment sets, and the PDFs were windowed by a spherical windowing function in order to reduce the folded signal caused by aliasing effect into FOV—our experimental results showed that these processes were part of the key to obtain more accurate orientation density function (ODF) by small number of DSI data points. As a preliminary study, the comparison of quality of DSI tractography has not been performed. Currently, orientations of fibers in each single voxel were focused because the accuracy of DSI tractography was closely related with the accuracy of ODFs, i.e. fiber orientations. It was assumed that if the accuracy of ODFs in each voxel was maintained, the quality of DSI tractography would be maintained as well. In order to compare ODFs, the first 3 maximum orientations of Set1 and Set2 were compared with gold standard by angles between them; this angular difference between orientations was adopted by this study as the criterion of similarity comparison.

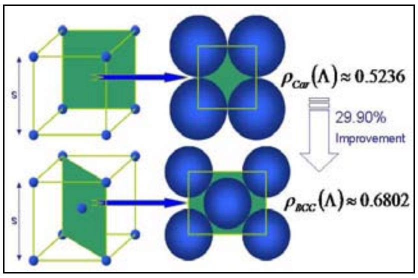
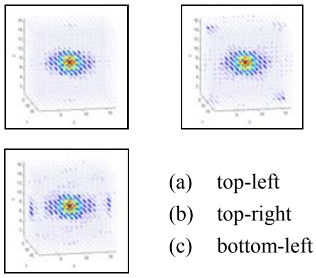
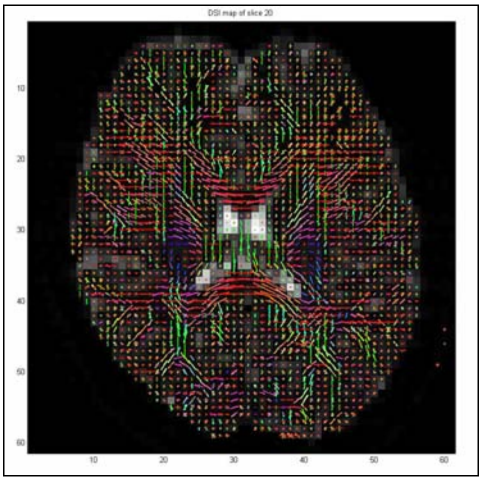


Fig.1 Comparison of sampling efficiency between Cartesian (top) and BCC (bottom) sampling lattice.



(a) top-left
(b) top-right
(c) bottom-left

Fig.2 PDF vs. Sampling Lattice of Q-Space: (Type/Points) (a) Cartesian, 515 (b) BCC, 259 (c) Cartesian, 251



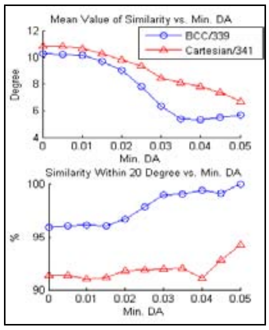


Fig.3 Similarity vs. Min. DA

Fig.4 DSI Map: Axial view of human brain—Reconstructed by BCC lattice with 339 samples in q-space.

Results

Figure 2 demonstrates the aliased pattern of a PDF taken from a voxel in the 1st slice, coordinate: (77, 77). When Set1 was set to be BCC sampling with 339 points, and Set2 was Cartesian one with 341 points (34% reduction of sampling points), the similarity analysis (angle between gold standard and Set1/Set2) was shown in Fig.3. The mean differences of angles between gold standard and Set1/Set2 were 5.4°/8.1° and 99.07%/92.06% voxels within 20° when all the voxels of diffusion anisotropy [5] higher than 0.035 was considered.

Discussion

Because maximum directions of isotropic PDF is more random than anisotropic one, the similarity (accuracy) and minimum diffusion anisotropy (DA) are heavily related (Fig.3) which means that the average accuracy is higher when voxels with lower DA are ignored. Experimental results showed that the sampling number of q-space may reduce up to 34% (515→339 points) with acceptable error (5.4° by BCC lattice) , and even if the same reduced number of sampling points was used, the accuracy improved 33.33% (8.1°→5.4°) from BCC sampling lattice to Cartesian one.

162 directions is used in the ODF calculation of this thesis, and it is believed that the greater difference between BCC sampling lattice and Cartesian one would be observed if angular resolution of ODF was higher. Moreover, comparison should be done by new DSI sequence of BCC sampling lattice, and acquire DSI data directly to compare the DSI accuracy between different sampling lattice on the same phantom in the future work..

Reference [1] Wedeen et al., ISMRM2000, p82. [2]Theussl, T., Moller, T, Groller, M.E., “Optimal Regular Volume Sampling,” Proceedings of the IEEE visualization Conference, San Diego, CA, USA, p91-98, 2001. [3] Lin et al., NeuroImage. 19:482-95, 2003. [4] Kuo et al., ISMRM2005, p391. [5]Kuo et al., ISMRM2003, p592.