Ordering of Multiple Diffusion Gradient Directions for High Resolution ADC Maps Using Golden Angle

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Introduction

Diffusion-weighted imaging (DWI) provides significant information about the tissue characteristics based on the diffusion properties [1, 2]. When DW images are used to calculate an apparent diffusion coefficient (ADC) map, multiple DW images from diffusion gradient (G_{diff}) directions should be acquired to resolve the anisotropic diffusion property. In order to reduce an imaging time for multiple DW images, a fast imaging method of EPI is usually used. However, EPI based DWI can generate image artifacts such as N/2 ghost artifacts and geometric distortions. In this abstract, a novel DWI approach using a radial trajectory is proposed for obtaining an accurate average ADC map with high- spatial resolution.

Methods

In the proposed method, DWI is acquired with a radial sampling trajectory. In conventional DWI with radial trajectories, each image is reconstructed from projection data acquired with diffusion gradients applied in a single direction. Thus, multiple DWIs should be obtained for the required number of diffusion directions. In the proposed method, however, different directions, $G_{diff,\,i}$ ($1 \le i \le N$, N: number of projection views) are used for N different projection views in a single DW acquisition, and the acquired data contains diffusion information of multiple diffusion directions. Then, the final image from projection data acquired with different diffusion directions contains diffusion property that is equivalent to the arithmetic mean of all applied $G_{diff,\,i}$ directions. Since the arithmetic mean and the geometric mean of different DW images can be approximately equal in the Taylor's series, the average ADC map, which is closest to the real ADC values, can be obtained by acquiring the projection data while sequentially changing $G_{diff,\,i}$ for each view of $1 \le i \le N$. However, the order of diffusion gradient directions may cause artifacts in the reconstructed DW image, if it aligns with the projection direction. To overcome this problem, the proposed method does not use similar $G_{diff,\,i}$ directions for adjacent projection views. More specifically, the $G_{diff,\,i}$ directions can have an even distribution in the 2D plane by using a golden angle scheme [3, 4], where each projection data is obtained using the diffusion gradient direction as illustrated in Fig. 1.

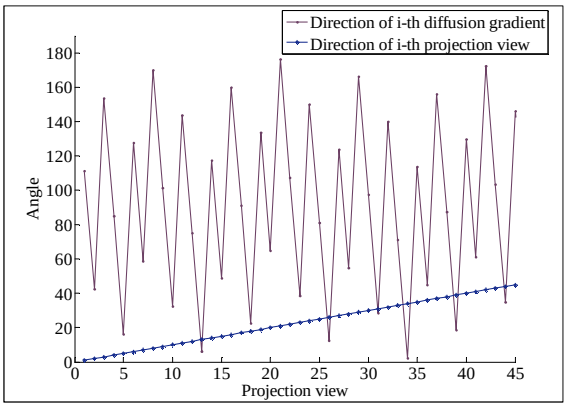

Figure 1. Proposed $G_{diff,\,i}$ directions for 180 projection views, $G_{diff,\,i} = \mathrm{mod}(180° \cdot i / 111.25°, 180°)$, where 111.25°: golden angle.

Results

To verify the feasibility of the proposed method, a diffusion model was generated based on the Shepp phantom with a matrix size of 256 x 256. As marked with a dotted box in Fig. 2 (a), six circles with diffusion terms were added to the Shepp phantom, where all pixels in each circle have the same anisotropic diffusion value. Figures 2(b) and (c) show DW images of an extremely anisotropic case. Figure 2(b) has severe artifacts in the diffusion region because adjacent projection views are acquired with similar G_{diff} directions, where the proposed method can reduce the artifacts as shown in Fig. 2(c). In figure 3, the error rates, (sum of absolute difference (SAD))/(proposed DW image), of various diffusion anisotropy values [5] are illustrated, where SAD is calculated from the proposed DW image and the average of 180 DW images separately obtained with different G_{diff} directions. The proposed method was also applied to a spherical water phantom at 15°C and in-vivo human brain on a 3.0 T MRI system (ISOL Technology, Korea), using the following parameters: TR/TE = 1700/110 ms, field of view (FOV) = 256 x 256 mm^2, 180 projection views with 180 G_{diff} directions, and 256 points for each projection view. The b-values of 0 s/mm^2 and 1170 s/mm^2 were used. Figure 4 shows (a) the DW image and (b) ADC map of the water phantom. A high-resolution ADC map of a human brain was also calculated as shown in Fig. 5(c) from the non-DW image (Fig. 5(a)) and the DW image (Fig. 5(b)).

Conclusions

A high-resolution ADC map could be calculated using a radial DWI sequence by obtaining information of various diffusion directions from only one imaging scan. The feasibility of the proposed method was evaluated through computer simulations and MR experiments. By employing a sequence based on the radial trajectories where every projection data is acquired with different directional diffusion gradient, the average ADC map with high spatial resolution could be obtained without any artifacts in a reduced scan time.

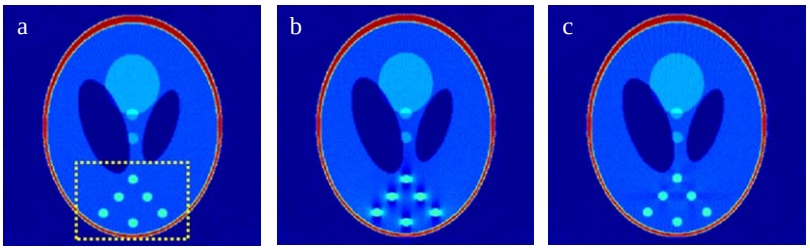

Figure 2. (a) A modified Shepp phantom, DW images when diffusion is extremely anisotropic (b) using sequential diffusion gradient direction, and (b) using the proposed method.

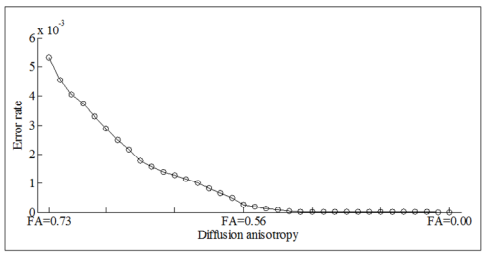

Figure 3. The error rates of the proposed method

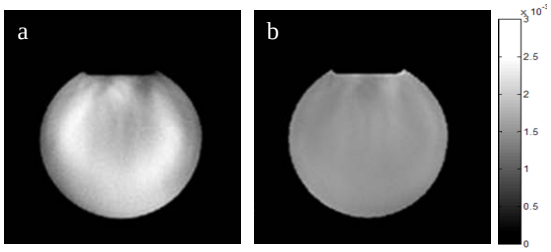

Figure 4. (a) A DW image, and (b) an ADC map of the water phantom at 15°C

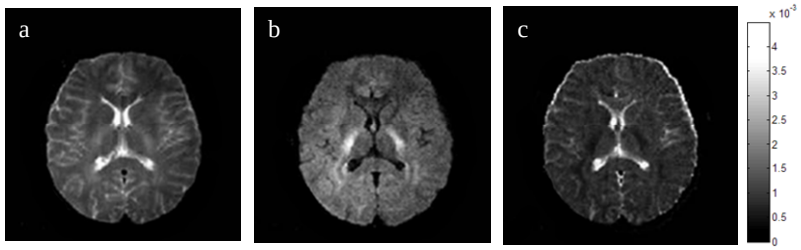

Figure 5. (a) A non DW image, (b) a DW image obtained by the proposed method, and (c) a high-resolution ADC map from (a) and (b)

References

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