Visualization of diffusion anisotropy using colored superquadric glyphs in DT-MRI

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Background: The goal of acquiring diffusion weighted images (DWIs) and calculating tensors is to analyze the structural information of the white matter in the human brain. Thus, it is important to effectively visualize the calculated information. However, it is a difficult process to visualize the direction and magnitude of diffusion tensors in a two dimensional (2D) screen [1]. Although there are several methods to visualize the tensors using cuboid, ellipsoid, cylinder, and superquadric tensor glyphs [2], the representation methods using glyphs alone are not clear enough to distinguish the directions of the tensors [3]. The RGB color sphere is generally used to help clarify the tensor directions but it cannot solve the directional ambiguity problem, which is the difficulty of distinguishing two vectors having 90° difference with each other (Fig.1), because it can assign the same colors to some vectors having 90° difference. Therefore, we propose a color sphere map which resolves the directional ambiguity problem while also fulfilling two requirements for color coding of the tensors, which are antipodal symmetry and uniform color difference.

Methods: We adopted the conventional CIE L*ab color sphere as a basis for the proposed color sphere because CIE L*ab color space is defined in 3D space and also shows uniform color difference. From the conventional CIE L*ab color space, we took the upper half of the sphere only, because the bottom half of the sphere was inappropriate to use due to its low luminance. The other half of the color sphere was then replicated with the color components of the upper half by applying the antipodal symmetry property. If the replacement is performed as it is, the reconstructed 3D color sphere should have a discontinuity area in the x-y plane (z=0). Since nearby color components in 3D space should have similar colors, we modified the range of luminance in the hemisphere to eliminate the abrupt changes before applying the antipodal symmetry property. As a result, a color space was generated as shown in Fig.2, which satisfies the antipodal symmetry while generally preserving the uniformity of the color space. We applied the color to the glyphs corresponding to the principal eigenvectors of the tensors by using the proposed color sphere and the pre-defined RGB color map as a reference.

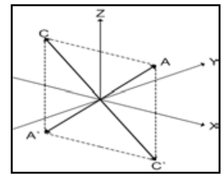


Fig. 0 Vectors A and C cause the directional ambiguity problem in RGB color sphere.

Result: We generated a simulation tensor model to show the application results of the proposed method using gradually changing eigenvectors and arbitrary eigenvalues of λ_1=0.7, λ_2=0.3, and λ_3=0.3 as shown in Fig.3. While the colors of the RGB model change abruptly around the origin from red to yellow as shown in Fig.3(a), those of the proposed color sphere show smooth changes as shown in Fig.3(b). We also acquired DWIs of a human brain using spin-echo diffusion-weighted EPI sequence having the matrix size of 128×128 and FOV of 256×256mm^2 with TE=219ms and TR=3000ms using 3 Tesla MRI scanner (ISOL Technology, Korea). The b value of 1000s/mm^2 was applied with δ=28ms, Δ=54.8ms, and gradient strength of 1.4G/cm in the directions of (0,1,-1), (1,1,0), (0,1,1), (1,0,1), (1,-1,0), and (-1,0,1). The color codings using the RGB model and the proposed color sphere were performed to the human brain data as shown in Fig.4(a) and (b), respectively, after noise reduction using the 3×3 smoothing filter. When compared with the conventional RGB color sphere, the proposed color sphere produced a tensor map that was more precise and easy to see. If we take a closer look to the area around the corpus callosum (CC), the tensor map coded with the RGB color sphere shows abrupt changes in colors even though the directions change gradually (Fig.5(a)) whereas the amount of change in colors and in directions seem to be more or less consistent in the tensor map coded with the proposed color sphere (Fig.5(b)).

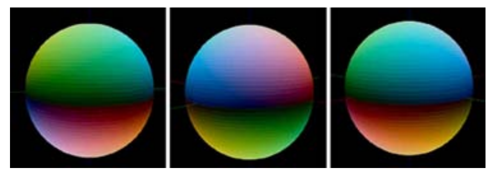
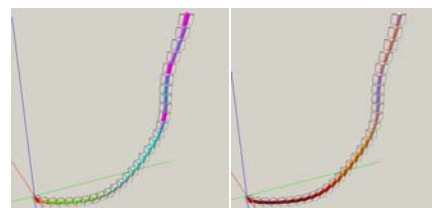


Fig. 2 Different views of the proposed color sphere



(a) (b)

Fig. 3 Simulation tensor models using arbitrary eigenvectors and eigenvalues are color coded using (a) the RGB color sphere, and (b) the proposed color sphere.

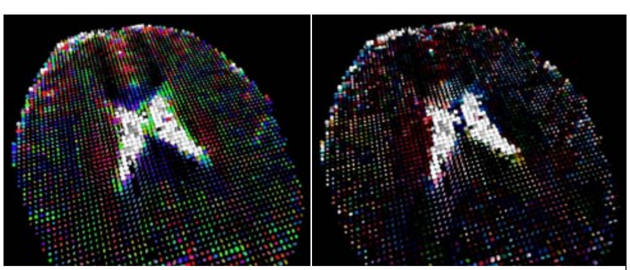
Discussion: Generally, there are two requirements of a color sphere model to visualize the diffusion tensors; the uniform color space property and the antipodal symmetry. The color sphere model should satisfy the uniform color space property because human visual system understands that abrupt changes in colors represent abrupt changes in directions. In other words, the nearby vectors in direction should be represented by small and uniform color difference. The color sphere model should also meet the antipodal symmetry criteria, where the color mapping should use the same color for the opposite directions, because the researchers have not yet been able to develop a diffusion-weighted imaging sequence which can distinguish the vectors of the opposite directions. Since the CIE L*ab color sphere satisfies uniform color space property [3], the proposed method satisfies the uniform color space property. We also designed the color sphere model satisfying the antipodal symmetry. Using the 3D glyphing method suggested by Gordon [2] together with the proposed color sphere model, we could successfully visualize the diffusion tensors in a 2D screen.

References:

[1] Denis Le Bihan et al., "Diffusion tensor imaging: Concepts and Applications", *Journal of Magnetic Resonance Imaging*, Vol.13, pp.534-546, 2001

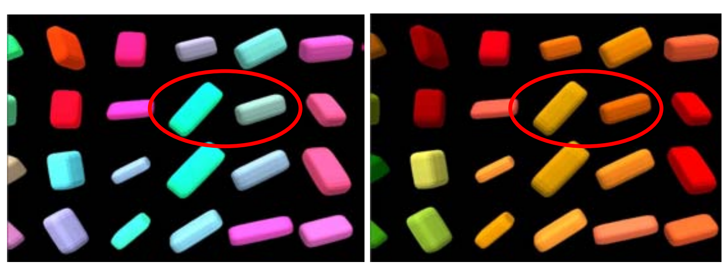
[2] Gordon Kindlmann, "Superquadric tensor glyphs", Proc. of Symposium on Visualization, 2004

[3] Sinisa Pajevic and Carlo Pierpaoli, "Color schemes to represent the orientation of anisotropic tissues from diffusion tensor data: Application to white matter fiber tract mapping in the human brain", *Magnetic resonance in Medicine*, Vol.42, pp.526-540, 1999



(a) (b)

Fig. 4 The color coding of superquadric glyphs using (a) the RGB color sphere, and (b) the proposed color sphere.



(a) (b)

Fig. 5 Magnified view of the area around the corpus callosum, color coded with (a) the RGB, and (b) the proposed color sphere.