Multi-Spherical MRI: Breaking the Boundaries of Diffusion Time
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Multi-Spherical MRI uses a separable Fourier Basis to reconstruct diffusion propagator \( P(\tau, \mathbf{r}; \mathbf{c}) \) from signal attenuation \( E(\mathbf{q}, \tau; \mathbf{c}) \), represented in coefficients \( \mathbf{c} \).

\[
\hat{E}(\mathbf{q}, \tau; \mathbf{c}) = \sum_{i} \sum_{k} c_{ik} \Phi_{ik}(\mathbf{q}) \mathcal{T}_{ik}(\tau) \quad \overset{FT}{\longrightarrow} \quad \hat{P}(\tau, \mathbf{r}; \mathbf{c}) = \sum_{i} \sum_{k} c_{ik} \Psi_{ik}(\mathbf{r}) \mathcal{T}_{ik}(\tau)
\]

\( \Psi_{ik}(\mathbf{r}) = FT(\Phi_{ik}(\mathbf{q})); 3D \) Fourier basis over \( \mathbf{q} \) and displacement \( \mathbf{r} \) \([3]\).

\( T_{ik}(\tau) \): Exponential diffusion time basis over \( \tau \) \([4]\).

We constrain the fitting of \( \mathbf{c} \) to respect boundary conditions of the signal and impose signal smoothness and sparsity:

\[
\text{argmin}_{\mathbf{c}} \int \left[ |E(\mathbf{q}, \tau; \mathbf{c}) - \hat{E}(\mathbf{q}, \tau; \mathbf{c})|^2 \right] d\mathbf{q} d\tau + \int \left[ \nabla^2 \hat{E}(\mathbf{q}, \tau; \mathbf{c}) \right]^2 d\mathbf{q} d\tau + \frac{\|\mathbf{c}\|}{1}.
\]

Where smoothness is imposed using closed-form Laplacian regularization.

Once fitted, all q-space indices \([3]\) can be estimated for any \( \tau \). As examples we show:

- Mean Squared Displacement (MSD), related to restriction
- Return-To-Origin Probability (RTOP), related to cellularity

2 Modeling the Multi-Spherical Space

3 In-Silico Results

We sampled this space on 35 different "shells", varying only \( g \), for different \( G \) ranging from [50-490] mT/m and \( \tau \) ranging from [9.1-18.3] ms.

4 Application In-vivo Mouse Data

After eddy current correction, we chose an ROI of 173 voxels in Corpus Callosum. After subsampling we find:

- Stable fitting errors from 400 down to 200 DWIs
- Expected trends for time-dependent MSD and RTOP

5 Discussion and Conclusions

- Multi-Spherical MRI allows for the characterization of diffusion restriction through time-dependent q-space indices.
- Additional signal or propagator constraints can be conveniently included in the optimization.

Through signal sparsity and smoothness, our approach can represent the multi-spherical signal with less samples, allowing more realistic acquisition schemes.

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References