Optimal acquisition order of diffusion-weighted measurements on a sphere

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Introduction A standard approach in diffusion-MRI is to acquire measurements spread evenly over a sphere in "q-space". Gradient directions may be found by minimizing the electrostatic energy of pairs of identically charged particles constrained to the surface of the sphere [1]. Dubois et al [2] modified this scheme to optimise the acquisition for unquiet subjects. The method provides improved results when the acquisition is interrupted, but moves the points away from the minimum energy configuration, which reduces the quality of the complete acquisition. We group the optimal electrostatic measurement directions into sets to be acquired in sequence. We divide the points into subsets with minimal electrostatic energy. Our primary purpose is to motion-correct each set independently. Each set gives us a separate diffusion tensor, which we can match to that from the other sets. However ordering the acquisition also improves the quality of partially completed scans, without reducing the quality of the complete scans.

Methods Our complete scan consists of 61 directions, which are the positions of 61 charge pairs on the sphere, arranged such that the electrostatic energy is minimum. We divide the pairs into four sets, one containing the first 16 pairs, the others containing 15 pairs. The measurements from each set are to be motion corrected independently, and, in order to get the best diffusion tensor estimate from each set, we aim to maximise the spherical coverage of each set, thus minimising the electrostatic potential of pairs within the same set. We optimise the cost function $E = \sum_{i=1}^{61}\sum_{j=1}^{61}\left[(1+\hat{\mathbf{q}}_i\cdot\hat{\mathbf{q}}_j)^{-0.5}+(1-\hat{\mathbf{q}}_i\cdot\hat{\mathbf{q}}_j)^{-0.5}\right]\delta_{ij}$,

which is the sum of the electrostatic potential between pairs *i* and *j*, whose orientations are the unit vectors $\hat{\mathbf{q}}$. The delta function δ_{ij} is 1 when *i* and *j* are in the same set, and zero otherwise. We search for the configuration with the lowest value of *E* by simulated annealing [3]. Starting from a random initial configuration we were able to reduce *E* by approximately 20% after a 24 hour computation on a standard Pentium IV workstation.

The brain data was acquired on a 3.0T scanner (GE Excite II platform running with G3M4 software) with an 8 channel head coil and 40 mTm^{-1} gradients. The imaging parameters were Δ = 29 ms, δ = 22 ms, b = 1200smm^{-2} and TE = 73 ms. The acquisition matrix was 96x96 and the field of view was 22 cm. Images were reconstructed to 256x256. Cardiac gating was employed, with triggering occurring at every QRS complex. Fifty-one, 2.7 mm thick slices were obtained in a TR of 30 RR intervals. Four separate series were acquired, with 4 dummy acquisitions being played out prior to the acquisition of the diffusion schemes. Unweighted data were interspersed evenly throughout the acquisition. Each series took approximately 6 minutes to acquire, and following transfer to a Sun workstation, underwent an in-plane registration to correct for in-plane eddy current effects.

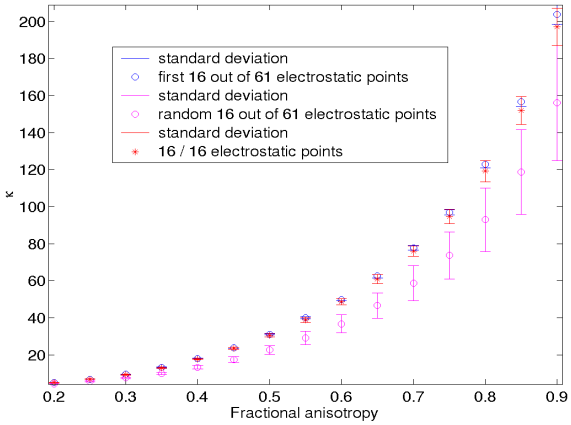

Figure 1: Concentration of fibre orientation estimates in synthetic data

We assess the impact of optimal ordering on the concentration of fibre-orientation estimates if only one of the sets is acquired. This corresponds to employing just 16 directions (out of 61) for reconstruction of the tensor. We compare the optimal set of 16 directions to 16 directions chosen randomly from the 61 point set, and an electrostatically minimized set containing a total of 16 directions. For each acquisition scheme we generate 5,000 sets of synthetic measurements from a cylindrically symmetric, anisotropic Gaussian distribution, add isotropic complex Gaussian noise, and take the modulus. We choose the variance of the noise such that the signal to noise ratio is similar to the brain data (which we estimate is 12 in the unweighted images).We fit the diffusion tensor to the noisy measurements and extract the set of principal directions. We quantify the concentration by fitting the maximum likelihood parameters of the Watson distribution: $f(\mathbf{x}, \boldsymbol{\mu}, \kappa \propto \exp[\kappa(\boldsymbol{\mu}^T\mathbf{x})^2]$, where the scalar parameter κ defines the concentration of the principal directions $\mathbf{x}$ about the mean principal direction $\tilde{\boldsymbol{\mu}}$ We repeat the process of adding noise and fitting the Watson distribution 25 times; for each iteration the principal diffusive direction of the synthetic signal is randomly oriented.

Results Figure 1 shows the concentration of fibre orientation estimates as a function of fractional anisotropy. The concentration of a scan with 16 measurements completed is higher on average and less variable when the measurements are optimally ordered. This means that we can improve the reliability of tractography in a partial scan. Figure 2 compares fractional anisotropy maps from a set of 16 optimally ordered acquisitions and a randomly chosen 16 measurements. The two images look similar, suggesting less benefit from optimal ordering when the objective of the scan is to quantify anisotropy.

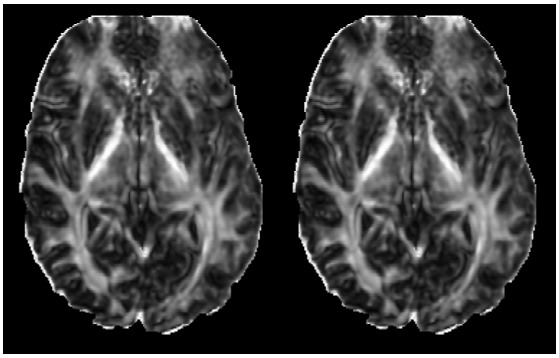

Figure 2: Fractional anisotropy map for tensors reconstructed from 16 optimal (left) and random (right) directions from the point set

Conclusions Optimizing the order of acquisition is worthwhile and can produce better estimates of fibre orientation from partially completed scans, without reducing the quality of the complete scan. The method of Dubois et al [2] may be preferable when the risk of scan interruption after only 6 measurements is high. However, our method is cost free, since it does not reduce the quality of the completed scan, and offers the opportunity to motion correct each set of measurements independently.

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References

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