# PANCHROMATIC SHARPENING OF FOD-BASED DEC MAPS BY STRUCTURAL T1 INFORMATION

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**Introduction:** Diffusion weighted imaging (DWI) acquisitions typically suffer from a lower spatial resolution, compared to their T1 structural counterparts, but provide unique angular information on the microstructure in each voxel. Consequently, researchers as well as clinical users may often find themselves switching back and forth between the traditional directionally-encoded colour (DEC) fractional anisotropy (FA) map and an aligned T1 map in order to navigate and identify the anatomy, or try their luck at overlaying them using (partial) transparency. In doing so, they rely mostly on the T1 intensities to define fine boundaries, while using the DEC for added specificity. The FA intensity's role is often reduced to providing a spatial cue to match both maps. This scenario is highly similar to the challenges encountered when visualising satellite image data. A typical solution used for that purpose is panchromatic sharpening, or pansharpening for short: a high resolution panchromatic image is fused with a lower resolution multispectral image, relying on the human visual system's relatively lower sensitivity to colour differences. Another application relying on this is chroma subsampling (e.g., used for video encoding and JPEG compression). We propose a pansharpening approach tailored to DEC information and (T1) structural data. However, we found that the DEC derived from the first eigenvector (FEV)[1,2] of the diffusion tensor can introduce false edges in the contrast (Fig.1), furthermore leading us to a more suitable DEC contrast based on the fibre orientation distribution (FOD) as obtained from constrained spherical deconvolution (CSD)[3].

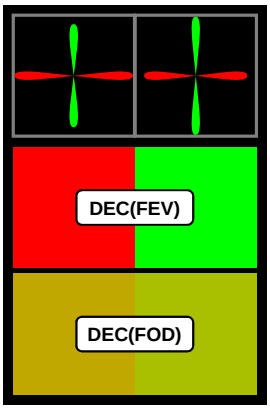


**Fig.1:** FODs in neighbouring voxels with slightly different relative lobe amplitudes, and the resulting DEC(FEV) and DEC(FOD) contrasts.

**Theory:** We denote the "traditional" unit DEC vector of the FEV by DEC(FEV); it evaluates to the elementwise absolute value of the FEV. Our FOD-based DEC vector, on the other hand, is defined as an FOD amplitude weighted mix of colours for *all* orientations:

$$\mathrm{DEC(FOD)} = \oint \mathrm{FOD}(u) \cdot \mathrm{DEC}(u) \cdot \mathrm{d}u \Big/ \left\| \oint \mathrm{FOD}(u) \cdot \mathrm{DEC}(u) \cdot \mathrm{d}u \right\|$$

The first step of our panchromatic sharpening approach consists of resampling either (FEV or FOD-based) DEC map to the grid of the T1-weighted structural volume. In this work, we apply cubic interpolation. This may, however, result in DEC vectors featuring non-unit norms; hence, we renormalise them at this stage. The resulting map is directly weighted by the T1 intensities; i.e., the T1 provides the luminance, while the DEC yields the chrominance information. This leaves the T1 information (and interpretation) *fully intact*.

**Data & processing:** DWI data of a single subject were acquired on a Siemens 3T scanner, with a voxel size of 2.5×2.5×2.5 mm³, and using a multi-shell acquisition scheme by applying diffusion weightings of b = 0, 1000, 2000, 3000 s/mm² respectively for 5, 17, 31, 50 directions. An extra b = 0 volume was acquired with reversed phase encoding. Additionally, a T1-weighted structural volume was acquired with a voxel size of 1×1×1 mm³. The DWI data was preprocessed using a state-of-the-art pipeline, including susceptibility-induced distortion correction using the reversed phase encoding volume[4], combined eddy-current induced distortion and head motion correction[5], and N3 bias-field correction[6]. The T1 volume was rigidly registered to the corrected DWI data (using a b = 0 volume) by maximising a normalised mutual information similarity metric. White matter (WM) FODs were obtained by applying multi-shell multi-tissue (MSMT) CSD[7] to the DWI data. The normalised DEC(FOD), as defined above, was calculated using discrete samples of the FODs evaluated for a set of 1281 directions (4th order icosahedral tessellation). This computation only takes a few seconds for the whole dataset. We also calculated the DEC(FEV) map from the tensor model. Both DEC maps were resampled to the 1×1×1 mm³ grid of the T1 volume, and the DEC vectors were renormalised. Finally, both maps were weighted by the T1 volume.

**Results & discussion:** Fig.2 presents the T1 map as well as the resampled/renormalised DEC contrasts obtained from the FEV/FOD, before they are fused. The FEV-based DEC contrast shows higher saturation because it is derived from single orientations, yet noisier "blobs" resulting from resampled noisy individual DEC voxels in regions where the FEV is less well-defined. This behaviour is similar to the example provided in Fig.1. After weighting by the T1 intensities, it becomes even more apparent that an often noisy contrast arises in the pansharpened FEV-based map, while the pansharpened FOD-based map provides better quality; hence we focus on the latter result. Fig.3 and Fig.4 show several other slices through the FOD-based pansharpened volume. Specific structures at the brim of (or even beyond) the DWI data's spatial resolution, e.g. the fornix, the optical chiasm and finer structures of the cerebellum, are still easily identified thanks to the T1 contrast. When looking closer, orientations in the cortex can even be clearly seen: we found this information is typically "greyed out" when observing single-shell FOD-based pansharpened maps (*not shown*), which may in fact be less overwhelming and overall easier on the eyes for some observers (a similar effect, if desired, could in principle also be achieved using multi-shell data). Finally, note that our pansharpened contrasts do not require fibre tracking (e.g., as in track-weighted imaging[8]), and *preserve the full interpretation and spatial coverage of the T1 information*.

**Conclusion:** A pansharpening approach tailored to DEC and (T1) structural data can work wonders, creating a single striking and easily navigated contrast image.

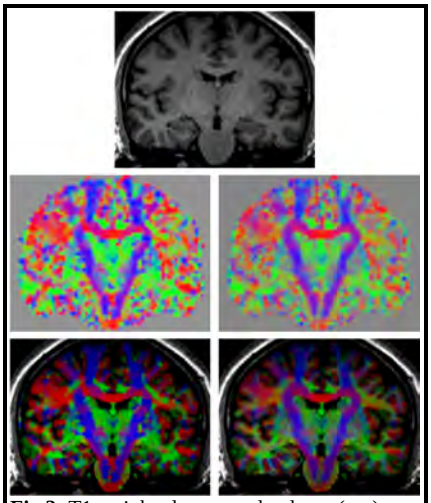

**Fig.2:** T1-weighted structural volume (*top*); DEC(FEV) and DEC(FOD), resampled to the T1 volume's grid and renormalised (*middle*); panchromatic T1 sharpened DEC(FEV) and DEC(FOD) contrasts (*bottom*). Note how this works out better for DEC(FOD).

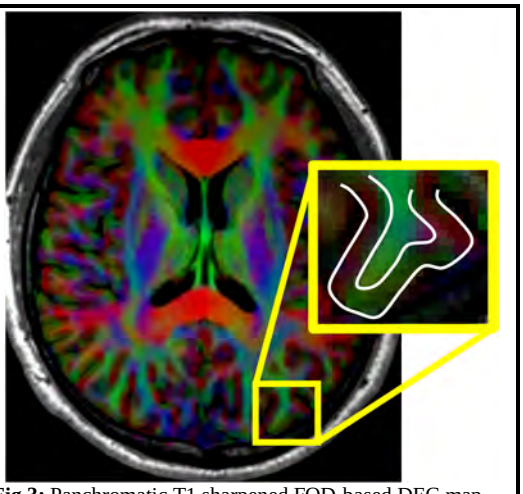

**Fig.3:** Panchromatic T1 sharpened FOD-based DEC map. At first sight, the amount of information may be overwhelming. Upon closer inspection, it can be seen that the colours often consistently indicate perpendicular directions in the cortical ribbon. Using *single-shell* CSD instead, this map can actually be *easier on the eyes*, but the details in the cortex appear more greyed out (*not shown*).

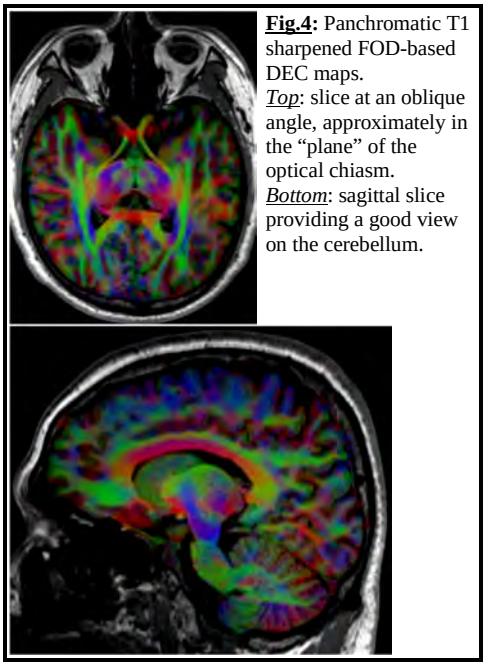

**Fig.4:** Panchromatic T1 sharpened FOD-based DEC maps.
*Top*: slice at an oblique angle, approximately in the "plane" of the optical chiasm.
*Bottom*: sagittal slice providing a good view on the cerebellum.

**References:** **[1]** Pierpaoli C, Proc. ISMRM 5, 1741 (1997), **[2]** Pajevic S and Pierpaoli C, MRM 42(3), 526-540 (1999), **[3]** Tournier JD et al., NeuroImage 35(4), 1459-1472 (2007), **[4]** Andersson JLR et al., NeuroImage 20(2), 870-888 (2003), **[5]** Andersson JLR et al., Proc. ISMRM 20, 2426 (2012), **[6]** Tustison NJ et al., IEEE TMI 29(6), 1310-1320 (2010), **[7]** Jeurissen B et al., NeuroImage 103, 411-426 (2014), **[8]** Calamante F et al., NeuroImage 59(3), 2494-2503 (2012).