A Modified Fuzzy Clustering Method for Modelling Partial Volume Effects in MRI Data

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Abstract: A method to find class centres in multi-echo image files by modelling partial volume effects was developed. Standard Fuzzy Clustering Method (FCM) [1] excels at rapidly finding such centres by using only the intensity histogram associated with image files. FCM is poor at finding class centres in MRI data because many voxels are represented by more than one tissue class. These "partial volume effects", which are not modelled in FCM, tend to bias the class centres away from the true centres. Partial Volume Fuzzy Clustering Method (PVFCM) was developed to model such partial volume effects in order to realize the rapid convergence associated with FCM while improving the accuracy of the resultant class centres. A variant of the Iterative Conditional Mode algorithm was developed which not only exhibits the rapid convergence of FCM but produces more accurate class centres, even in the presence of significant partial volume effects.

Background and Theory: In FCM a "class centre" is defined for each class *k* by its intensity value in each of the image echoes. The intuition is that pixels whose intensity is close to one of these classes is likely to be a member of that class (in this paper spatial relationships such as "close" are referring to the relative positions of features in the intensity histogram). FCM begins by randomizing the class centres and then repeatedly applies the following procedure until the class centres converge:

(1) for each pixel *i* and for each class *k*, find the membership U_{ik} using some function of the distance to each class centre as the weight;

(2) use U_{ik} calculated above to calculate the new class centres, which will be the mean intensity of all pixels i in class *k* with weight U_{ik}.

The defining modification of PVFCM is to introduce additional classes, one joining each pair of existing classes. The existing classes are called "pure classes" as they model membership in a single tissue (e.g. white matter (WM), grey matter (GM), cerebrospinal fluid (CSF), and "background"). The new classes which are formed from two pure classes are the "partial volume classes", and they model the partial volume effects between two pure classes. Voxels whose intensities lie between two pure classes are not assigned strictly to one or more of the pure classes; they may instead be classified in part as belonging to one or more partial volume classes as well. For example, a voxel that is located at the midpoint of the line segment joining GM and CSF may be modelled as 100% GM-CSF membership, instead of, for example, 50% GM and 50% CSF in the case of FCM.

Methods: 1311 MS patient MRI scans from various sites were selected and processed for analysis. The scans were proton density weighted volumes of 24 slices with 5 mm thickness, acquired using a multi-echo spin-echo pulse sequence with TE λ 20/80ms and TR λ 2600ms (FOV λ 23cm, 192%256 acquisition). Image processing was performed on all scans and included noise filtering and RF inhomogeneity correction using standard methodology. Finally technicians masked out non-brain tissue as "background" using a semi-automated program. One scan and its associated histogram are displayed as Figures 1-4 below. Three classes were modelled: the pseudo-class "background", CSF, and a single class WM/GM representing white matter and grey matter. We believe this represents the simplest case that illustrates the performance of the two algorithms and provides a minimally interesting useful result. Note that the method itself is not aware of the class labels above and just operates "blindly" with the three classes; it is only by subsequent inspection of the final result that we can associate these three classes with the ones mentioned above. This is true in general for FCM, and is also true for PVFCM. Also note that convergence is rapid in both methods and takes no more than about 15 iterations.

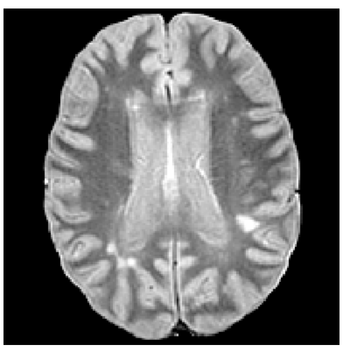

Figure 1

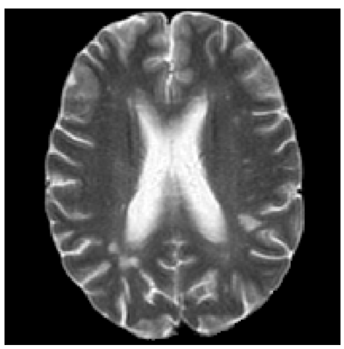

Figure 2

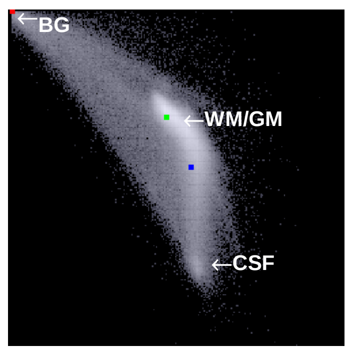

Figure 3

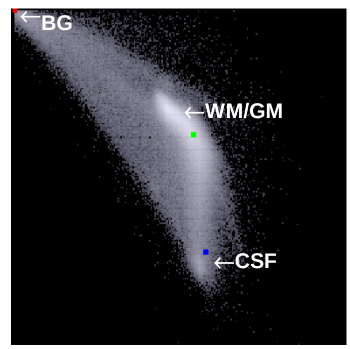

Figure 4

Figure 1 is the PD-weighted echo for slice 16 of one scan. The associated T_2-weighted echo is shown in Figure 2. The log-scale intensity histogram for all slices of the same scan is shown in Figures 3 and 4. Figure 3 shows the resulting class centres using FCM, and Figure 4 shows the resulting class centres using PVFCM. In Figures 3 and 4 the final class centres found are displayed as coloured dots: the red dot is "background", the green dot is WM/GM, and the blue dot is CSF. The labels in Figure 3 and Figure 4 are the true class centres: BG="background", WM/GM, CSF.

Results: The FCM and PVFCM methods were applied to all 1311 scans. As our standard for comparison, qualified technicians used a semi-automated program to produce masks of the ventricles, which provided baseline truth for CSF intensity (we expect the ventricles to consist primarily of pure CSF voxels). For each scan, we calculated the percentage difference between the CSF class centre and the baseline intensity. The mean distance from baseline for CSF centres found using FCM was 23.3% of the baseline value. The mean distance from baseline for CSF centres found using PVFCM was 12.2% of the baseline value. Thus, on average, PVFCM outperformed FCM by a factor of 1.91.

Conclusion: The results indicate PVFCM improves upon FCM in finding the CSF class centre. This is probably due to the pervasive partial volume effects present in MR images, particulary in the sulcal CSF. We expect in general that all classes would similarly benefit from the partial volume modelling. It is therefore proposed that PVFCM is an appropriate model for histogram-based fuzzy clustering in the presence of significant partial volume effects.

Future Work: The PVFCM algorithm is designed to accommodate additional class centres and echoes, which could be used to separate the WM/GM class into two pure classes. Another variant would be to exclude certain partial volume classes based on *a priori* anatomical knowledge (e.g. there should be very few voxels containing both WM and CSF).

Acknowledgements: We wish to thank Serono for supporting the MS study from which the data was obtained.

References: [1] Bezdek J. C. *et al.* Med Phys 1993, **20(**4), pp.1033-1048.