

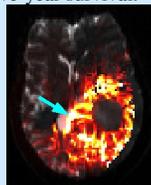
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INTRODUCTION

Clinical Motivation: Our overall goal is to predict spread of cancer in the brain to improve stereotactic radiation therapy of primary cancers for which our best current treatment offers only a 2% five-year survival.

Computational model: A random walk model is being developed of glioma cancer cell infiltration based on MR-DTI for the purpose of predicting the location of tumor recurrences [1] (see poster #PS-8A-199). The objective of this work is to better determine the anatomy of the each patient's brain as a boundary constraint on our model to prevent the migration of cells into the ventricles, outside the exterior brain surface or across the internal sulci and folds in the brain.



Limitation of prior work: A variety of automated segmentation techniques have been applied previously to extract features of interest from digital images including deformable models (snakes), histogram-based clustering, region growing methods, transformation of atlases and watershed transformation. However, the complexity of the 3D structures along with variability in anatomy between individuals, disruption of normal anatomy due to presence of large tumors and/or surgical intervention and MRI related noise and inhomogeneity have so far thwarted automated segmentation using these traditional methods.

Hypothesis: The hypothesis that is proposed in this study is that segmentation of ventricles and the outer brain contour in human MR images can be achieved using automatic level set segmentation and 3D flood-fill algorithm.

MATERIALS & METHODS

Ground Truth: For the purpose of this work, due to the lack of pathological studies to support the anatomic structure, we performed slice-by-slice human tracing of the brain mask as our ground truth. Manual segmentation of the brain mask was performed using the Polygon Toolbox of The Insight Segmentation and Registration Tool Kit (ITK SNAP) software. In order to avoid any human bias that may get into the manual segmentation process, it was performed by an independent observer.

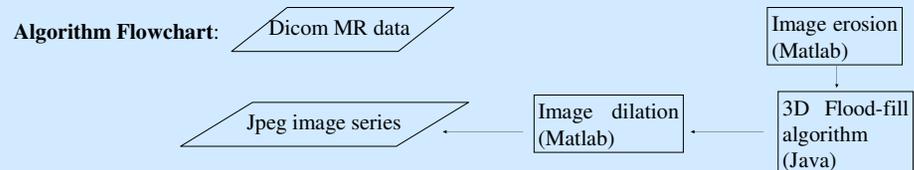
Mumford-Shah level set model: Level set model automatically evolves an initial curve towards the lowest potential of an energy function defined as follows:

$$E(C1, C2, \phi) = \mu \int \delta(\phi) |\text{grad}(\phi)| dx dy + \nu \int H(\phi) dx dy + \lambda_1 \int |u_0(x, y) - C1| 2 H(\phi) dx dy + \lambda_2 \int |u_0(x, y) - C2| 2 (1-H(\phi)) dx dy$$

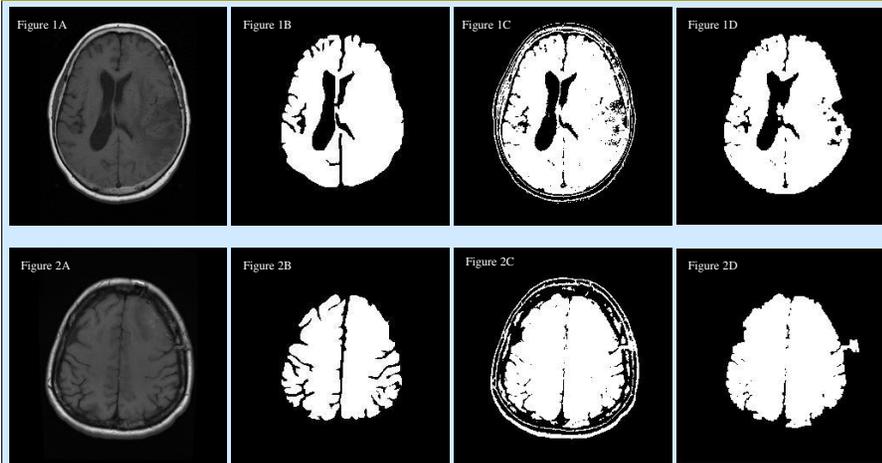
where $\phi(x, y) < 0$ for x, y within the contour (level set function)
 $\phi(x, y) > 0$ for x, y outside the contour
 $\phi(x, y) = 0$ for x, y on the contour
 $C1, C2$: mean of original image u_0 inside and outside Γ respectively.
 μ : scale parameter
 $H(\phi)$: Heaviside function
 $\delta(\phi)$: Delta function: derivative of the Heaviside function
 $\mu, \nu, \lambda_1, \lambda_2$: non negative parameters

3D Flood-fill algorithm: Flood-fill algorithm is a region growing segmentation method which starts at a seed point and identifies connected voxels based on a threshold value as single object.

Training & Test data sets: Four brain MR image data sets were obtained in glioma cancer cell patients using a conventional T1-weighted acquisition with 24 slices and in-plane resolution of 256 x 256 (0.86x0.86x6 mm)



RESULTS



Results shown from two patient data sets used in the testing process:

Figure (1&2) A shows the original Dicom image of one slice
 Figure (1&2) B shows the manual segmentation of the ventricles and the outer brain contour of the corresponding slice
 Figure (1&2) C shows the results of automatic 3D level set segmentation
 Figure (1&2) D shows the final output after erosion, 3D flood-fill and dilation on the level set segmented image

Statistical measures:	Jaccard Index	Dice Coefficient	Sensitivity	Specificity
	$ A \cap B / A \cup B $	$2 A \cap B / A + B $	$TP / (TP + FN)$	$TN / (TN + FP)$
Data set 1	0.6654	0.7991	0.9306	0.9364
Data set 2	0.6618	0.7965	0.8119	0.9586

Optimized values of parameters used: $\mu = 250, \lambda_1 = 0.6, \lambda_2 = 0.9$

DISCUSSION

T1 weighted images were used because of their higher contrast in the ventricular and its surrounding region, compared to other types of MR images. The constant value of u was calculated as the average of u_0 over the sub-regions inside and outside the level set contour. The values of $\mu, \lambda_1,$ and λ_2 were obtained by optimizing them on the training data sets. For simplicity ν was taken to be 0. The algorithm segmented the boundary of 3D ventricles in under 8 minutes on a Windows-based PC running Matlab, compared to the manual segmentation of the ventricles which took approximately 30 minutes.

CONCLUSION

We have designed a novel algorithm that performs automatic segmentation of the outer brain and the ventricles in human brain MR images based on the Mumford-Shah level set model and a semi-automated 3D flood-fill algorithm. The results of the algorithm show a successful 3D segmentation of the ventricles and outer brain contour from our human brain MR image data sets. Our future goal is to improve the algorithm by better optimizing the parameters so as to control any segmentation leakage, also to use a smooth homogeneous value of u over sub-regions inside and outside the level set contour and to apply the technique to a greater variety of patient data sets.

ACKNOWLEDGEMENTS

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