Abstract

Automated brain lesion detection algorithms have the potential to act as a valuable tool for assisting radiologists in reading MR scans for abnormalities such as brain metastases and MS lesions, however, they require prior brain extraction in order to lower computational cost and prevent high false positive rates. We have developed a method that combines atlas-based techniques with image edge detection capabilities for the purpose of performing brain extraction while preserving the MR appearance of lesions. In our approach, patient MR datasets are registered to a reference MR dataset with an affine (9-parameter) transformation and the optimal transformation is applied to a 3D brain surface that was generated by the meticulous manual contouring of the reference dataset in the coronal and axial directions. The datapoints from the transformed brain surface are divided into slices for use as the starting control points for a series of snakes corresponding to the slices of the testing MR dataset. Snakes are then optimized through the minimization of internal and external energies to provide the final contouring of the testing MR dataset. We were able to achieve a Jaccard Index value of 0.87 and a Dice Coefficient of 0.93 on our testing dataset where 76.6% of brain-adjacent regions of the branches of the internal carotid arteries and dural venous sinuses (common sources of detection algorithm false positives) were removed successfully. These preliminary results indicate that our 3D brain contouring approach has the potential to develop into an accurate and efficient method of extracting the MR brain prior to the employing of a lesion detection algorithm.

Introduction

Constant advances in scanning technology and techniques have enabled MR imaging to become a powerful clinical tool for detecting and monitoring brain lesions such as metastatic tumors. Consequently, automated lesion detection algorithms have become an area of rapidly growing interest for the purpose of assisting radiologists with the ever-increasing patient scan reading workload. Brain segmentation is an important precursor step for automated MR lesion detection algorithms as the effective extraction of the brain lowers computational cost and dramatically reduces the number of false positives in the final results of a detection algorithm. Although several fully-automated techniques for brain extraction have been developed, these approaches were not designed specifically to be accurate when used with brain images containing anatomical discrepancies due to the presence of brain lesions. For example, segmentation programs that rely too heavily upon non-specific intensity thresholding can lead to the removal of lesions from the final extracted brain while strictly atlas-based methods may fail in extracting patient datasets effectively when there are large deviations from normal brain anatomy caused by the presence of lesions. Our approach integrates 3D brain atlas matching with the edge detection features of a snake for the goal of producing an accurate brain extraction that preserves lesion morphology while removing the anatomic structures that commonly result in false positives when applying an automated lesion detection algorithm.

Methods

All anatomical MR scans utilized for the brain extraction experimentation done in this work had been accumulated previously at our institution and were collected with a 1.5T GE Genesis Signa scanner using a spoiled gradient echo pulse sequence (SPGR). Manual contouring was performed rigorously on 60 coronal MR slices (in-plane resolution of 0.43 mm and slice thickness and separation of 2.5 mm) and 23 axial MR slices (in-plane resolution of 0.86 mm and slice thickness and separation of 5 mm) from a single patient dataset where the branches of the internal carotid arteries and the dural venous sinuses were excluded as they are common sources of detection algorithm false positives (see Figure 1). A 3D brain surface was constructed from the 35,092 surface datapoints generated by this slice-by-slice contouring (see Figure 2). The extracted reference dataset that was used to construct the brain surface was then registered to an unprocessed testing dataset taken from a different patient through the use of a 9-parameter affine transformation with a correlation coefficient as the similarity measure. The optimal transformation produced by this registration process was applied to the 3D brain surface and the datapoints from the transformed surface were then employed as the starting control point coordinates for a series of 2-D snakes corresponding spatially to each coronal slice of the testing MR dataset. Finally, the 3D extraction of the testing dataset was completed by optimizing each snake to the contour of each corresponding testing dataset MR slice through a minimization of the snake's internal and external (image) energies:

$$E_{Snake} = \int_0^1 w_{int} E_{int}(s) + w_{image} E_{image}(s)\, ds \qquad E_{int} = \alpha \left| \left(\frac{dv}{ds} - d_0 \right) \right|^2 + \beta \left| \frac{d^2 v}{ds^2} \right|^2 \qquad E_{image} = \nabla^2 I(x, y)$$

where $v(s)$ represents the snake, s is the distance along the snake, α is a measure of the snake elasticity, β is the stiffness of the snake, d_0 is a baseline distance between points along the snake, and the internal and image energy terms are multiplied by weighting factors (w) to account for their level of contribution.

Results/Discussion

A primary goal of this work was to establish the efficacy of our extraction approach, which combines a model-based brain shape analysis with the edge detection capabilities of a snake, in separating the brain mass from surrounding non-brain structures. In particular, our approach was focused towards improving the results of lesion detection algorithms by removing the dural venous sinuses and the branches of the internal carotid arteries from extracted datasets while avoiding the loss of brain mass areas due to structural abnormalities caused by lesions of significant size and brightness. Overlap analysis was performed on the testing dataset extracted by our algorithm as compared to a gold standard extraction of that same dataset performed manually leading to the calculation of a Jaccard Index value of 0.87 and a Dice coefficient value of 0.93. In addition, 76.6% of brain tissue-adjacent dural venous sinus and internal carotid artery branch voxels were removed successfully.

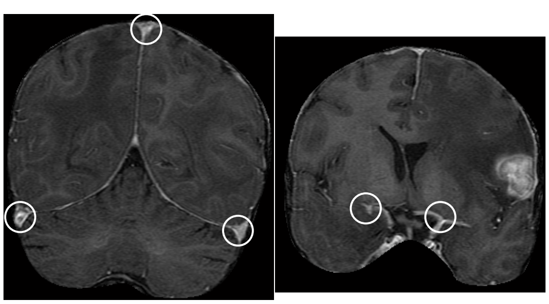

Figure 1. Example anatomical locations of dural venous sinuses (left image) and branches of the internal carotid arteries (right image) whose removal were a major focus of our extraction approach as they represent common sources of false positives for automated lesion detection algorithms.

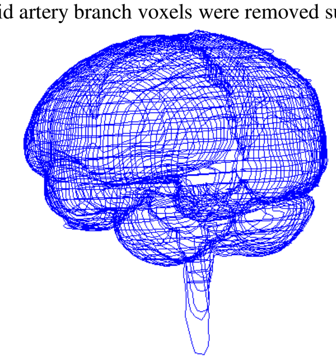

Figure 2. 3D brain surface generated by datapoints from manual contouring of reference dataset's coronal and axial images.