Automated segmentation of the brain from T1-weighted MRI using Bridge Burner algorithm

A. Mikheev[1], H. Rusinek[1], R. Grossman[1]
[1]Radiology, NYU School of Medicine, New York, NY, United States

Clinical and research neuroimaging applications require the ability to accurately extract the brain tissue from the image data. In patients suffering from traumatic brain injury, multiple sclerosis, or dementia, brain volume provides a useful estimates of swelling, atrophy, or response to treatment. "Brain stripping" is also a required first step in retrospective registration of structural MRI to functional brain images (obtained from fMRI, PET, SPECT, MEG, or ECG) and in retrospective algorithms that correct for low-frequency spatial non-uniformity of MR signal. This paper describes and validates *Bridge Burner*, a fully automatic algorithm for segmenting the brain from T1-weighted MRI.

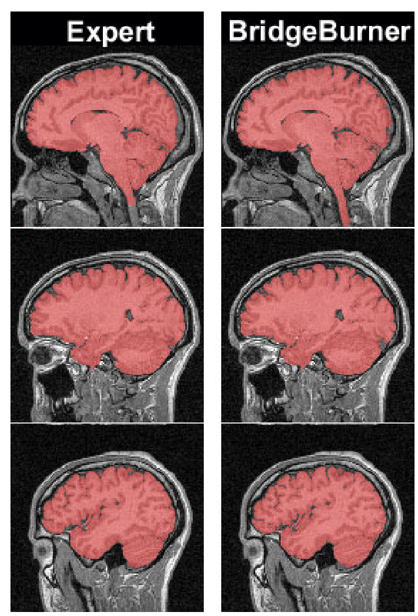
Methods

After resampling the image to isotropic voxels, a preliminary thresholding is applied to create the binary mask *M* (Fig. A). *M* includes all cerebral gray and white matter but excludes the cerebrospinal fluid, air and some fat. Some non-brain tissue such as muscle, skin, and blood vessels will also belong in *M*. These tissues are topologically connected to the brain through narrow "bridges" (see arrows in Fig. A). The next task is the detection of 3D edges (Fig. B). Edge detection is done using a 3D Canny edge algorithm [1]. The set *M* is then subjected to *p* passes of a morphological erosion operation, in which voxels are marked as "peeled" and the surface of set *M* is repeatedly updated. The parameter *p* is set to exceed the maximum width of the bridges that connect the brain to other tissues (Fig.C, *p*=3). In the next step we identify and order by size all connected components of the eroded set. We hypothesize that the maximum connected component (MCC) no longer contains nonbrain voxels (Fig. D). Finally, we apply the morphological growth operator to offset the effects of erosion (Fig. E). We grow MCC by adding back only those voxels that were previously marked as "peeled". The growth is constrained so that the wavefront is not allowed to cross the 3D edges. This last step provides a mechanism for brain stripping that is independent of connectivity and improves the accuracy of results (see below). Algorithm was implemented in C++ on a MS Windows system.

To validate this algorithm, seventeen healthy volunteers (9 women, 8 men; mean age: 32.8 years; range: 18.4-47.8) underwent brain MRI on a 1.5 Siemens Vision. The protocol included a standard sagittal T1-weighted MPRAGE sequence (TR/TE/FA 9.7ms/4 ms/15°, SL 1.5 mm, FOV 210×210 mm, 256×256×128 matrix). Each brain was also traced manually by an expert neuroanatomist. Manual segmentation required over one hour of interactive editing per case. Oversegmentation (false positive) and undersegmentation (false negative) voxel masks were constructed, visually inspected, and analyzed for volume errors.

Results and Discussion

The mean (± std. deviation) absolute discrepancy between *BridgeBurner* and the expert neuroanatomist was 26.7±6.6 ml. Misclassified voxels represented 2.14%±0.49% of the true brain volume. Errors were consistently located in the sinuses of the dura matter and in the sella turcica. The oversegmentation error was with 15.7±4.0 ml and the under-segmentation error was 11.0±4.5 ml. When running *BridgeBurner* without 3D edge detecytion, the total error increased significantly to 2.43% of the true volume (paired T-test, $p<0.001$, T=4.31). On a standard personal desktop computer with 2.4 GHz processor and 512 Mb memory, the processing speed is 16 seconds with, and 11 seconds without surface processing. Thus, the algorithm has a better accuracy and more than 100 times faster than the best state-of-the-art brain segmentation methods such as McStrip[2-5].



References

1. Monga O.et al. *Image and Vision Computing* 4(9): 203-214; 1991.
2. Smith, S.M. *Human Brain Mapping* 17:143- 155, 2002.
3. Shattuck D.W. et al. *Neuroimage.* 13(5):856-876, 2001
4. Rehm K et al. *Neuroimage*. 9(6) S86, 1999.
5. Boesen K. et al.. *Proceedings 9-th Intern. Conf. Functional Mapping of the Human Brain*, June 19- 22, 2003, New York, NY.