Comparison of Methods of Registration for MRI Brain Images

We used a fully automated application for the registration of magnetic resonance images (MRI) for Alzheimer patients who were given the drug, *Aricept*®. Two different methods for image registration were implemented and compared: affine (rigid-body transformation) and nonlinear registration.

The affine registration algorithm is linear and is generated by means of an amplitude-modulated phase-only filter (AMPOF). The AMPOF is an extension of the classical match-filter (CMF) and is used as the correlation filter for the affine registration method.

The nonlinear registration method uses an elastic transformation based on a displacement vector field generated by means of Navier-Stokes continuum-mechanics fluid flow models. In contrast to other nonlinear warping methods using elastic transformations, we implemented the AMPOF shift coefficients as a translation to aid in the detection of feature boundaries, which are segmented by means of statistical feature extraction methods.

With our new validation method, we can quantitatively compare the performance of the affine and nonlinear registration algorithms using root-mean-squared (rms) error, where the output registered MRI is subtracted from the template MRI. The resulting pixel intensity difference is used to calculate the rms error of the image registration. Additionally, the registration validation is taken a step further by implementing 3-D spatial transform models and volume rendering to visually verify registration results for the Alzheimer MRIs.

Project Goals

The goal is to evaluate affine and nonlinear algorithms for image registration that may be used to detect anatomical variations resulting from pathology in the brain. Such variations could be used in the diagnosis of Alzheimer's and other central nervous system diseases, and to detect group-specific patterns of anatomic or functional alterations.

Relevance to LLNL Mission

Affine and nonlinear registration algorithms have distinct applications in the areas of interest to LLNL programs, such as medical technology, homeland security, and nondestructive evaluation. These algorithms can be used to extract features relevant to detecting aberrances within armory, such as finding cracks or defects in nuclear weapons.

FY2005 Accomplishments and Results

Affine Registration. AMPOFs used for pattern recognition have demonstrated better discrimination capabilities than CMFs. The flowchart in Fig. 1

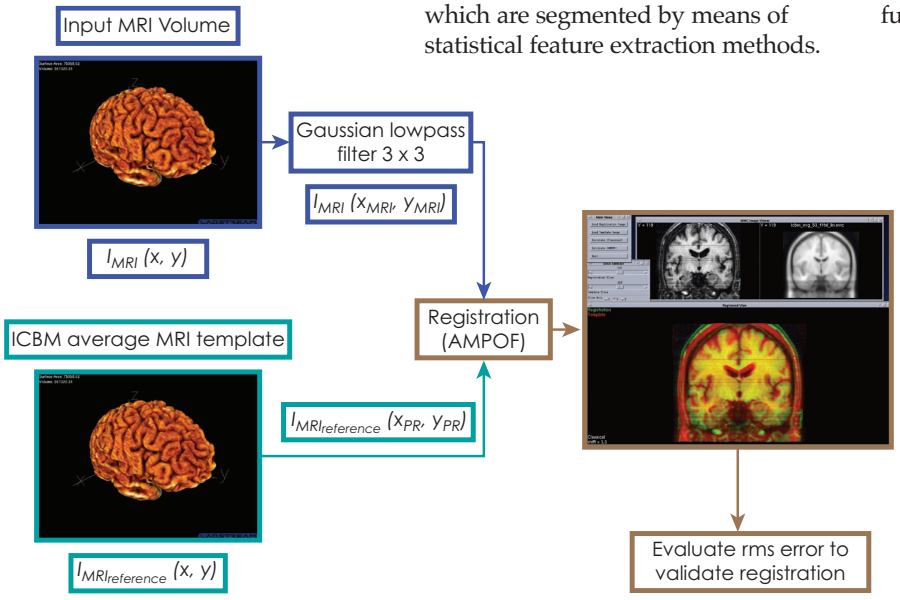

Figure 1. Affine registration using AMPOF.

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illustrates the affine registration method. The quality of the registration is quantified as an rms error calculated from the pixel intensity differences between the registered output MRI and the template MRI.

Nonlinear Registration using Continuum-Mechanics Warping. For nonlinear registration, the MRI volume from each patient is morphed to areas on the template image volume using a continuum-mechanics flow model. The flow model uses a field of normal vectors (perpendicular to surfaces of image intensity features in the 3-D volume) to steer shapes of intensity data from the patient into corresponding shapes in the International Consortium of Brain Mapping (ICBM) template. The steering is achieved through an iterative solving of a modified Navier-Stokes fluid flow for elastic media.

The resulting newly morphed patient image may be explored via interactive volume rendering visualization, which has been incorporated into this project's MRI registration software. The visualization also enables the user to superimpose the new image with the ICBM template, showing exactly how the intensities match between the two. An overall metric of rms error of the differences in intensities between the two volumes is also computed. The metric is recorded for each set of MRI images. Figure 2 shows a snapshot of the volume rendering of patient data during the morphing process, and the Automated Continuum-Mechanics flowchart.

Our conclusion is that, for MRIs, the nonlinear registration using continuum-mechanics warping models is approximately 31% more efficient than the affine (linear) registration method.

Related References

1. Thompson, P. M., and A. W. Toga, "Alzheimer's Disease: MRI Imaging of Progressive Brain Change," Encyclopedia of Neuroscience, G. Adelman and B. H. Smith, Eds., November 2003.
2. Thompson, P. M., K. M. Hayashi, G. de Zubicaray, A. L. Janke, E. R. Sowell, S. E. Rose, J. Semple, D. Herman, M. S. Hong, S. Dittmer, D. M. Doddrell, and A. W. Toga, "Dynamic Mapping of Alzheimer's Disease," *Proceeding of the 19th Collogque Medecine et Recherche*, IPSEN Foundation, Paris, France, March 2003.
3. Thompson, P. M., J. N. Giedd, R. P. Woods, D. MacDonald, A. C. Evans, and A. W. Toga, "Growth Patterns in the Developing Human Brain Detected by Using Continuum-Mechanical Tensor Maps," *Nature*, **404**, 6774, March 9, 2000.
4. McClay, W. A., III, A. A. S. Awwal, S. Burkhart, and J. V. Candy, "Optimization and Improvement of FOA Corner Cube Algorithm," *Photonic Devices and Algorithms for Computing VI, SPIE*, Denver, Colorado, August 2004.
5. Candy, J. V., W. McClay, A. A. S. Awwal, and W. Ferguson, "Optimal Position Estimation for the Automatic Alignment of a High Energy Laser," *Journal of the Optical Society of America*, **22**, 7, pp. 1348-1356, July 2005.

FY2006 Proposed Work

We will continue to create new models to solve registration problems of interest to LLNL programs.

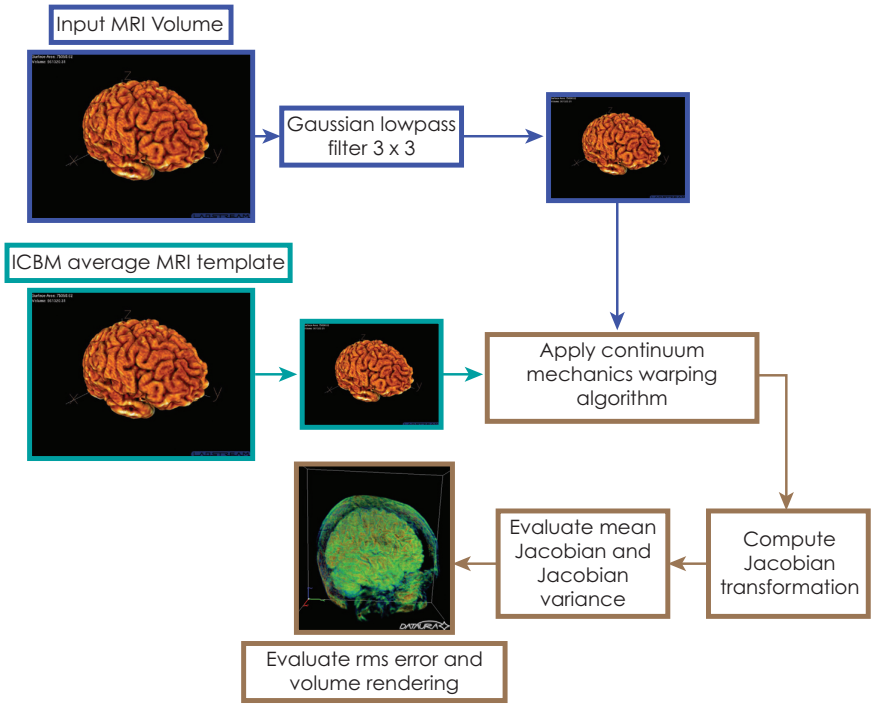

Figure 2. Automated Continuum-Mechanics flowchart and MRI volume rendering to validate nonlinear warping.