Automatic Image Registration Based Upon an Elastic Finite Element Formulation

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Abstract

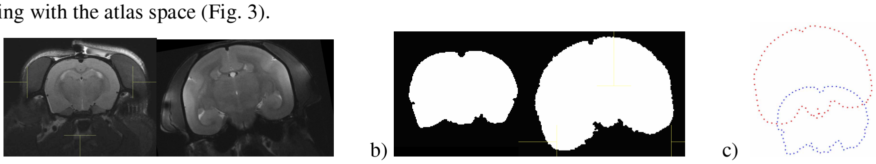
An automatic non-rigid body registration is presented using a linearly-elastic finite element formulation. An MRI volume set is passed through a Pulse Coupled Neural Network which automatically crops each slice of the brain. The perimeter contour is orientated to an atlas contour based on a least-squared shape analysis. A 2D finite element mesh is automatically created on the image slice. The linear elastic formulation for plane strain is applied to the finite element mesh. Iterative incremental displacements are applied on the boundary with the finite element formulation dictating the domain alignment. The process terminates once the subject perimeter is tagged to the atlas perimeter. The method was successfully tested on magnetic resonance images (MRI) of rat brains. This model-based registration algorithm does not require manually created landmarks.

Background

In order to make reliable analyses and diagnoses for longitudinal studies or composite studies of multiple subjects, alignment of subjects to a reference is required. Numerous medical image registration strategies have been developed. Image registration is the process of finding a geometrical transformation that aligns two or more images based upon a variety of similarity measures. The most common alignment strategy is a rigid body or affine process that produces a 4x4 homogeneous transformation matrix. However, this strategy does not allow for non-uniform or differential deformations within the image domain. A finite element representation of the image set offers numerous opportunities for alternative alignments. We present a method that performs cropping, finite element mesh deployment, and application of a plane-strain elastic formulation to align subjects to a reference. The process is automatic, reliable and does not require user intervention.

Methods

The atlas and subject images (Fig. 1a) are cropped by an automatic cropping process using a Pulse-Coupled Neural Network (PCNN)[1] which creates a mask of the cropped area (Fig. 1b). A perimeter contour of each mask is established using a fixed set of uniform boundary line segments (Fig. 1c). The change in angle of each adjacent boundary line segment in the subject is compared to that in the reference. The subject segment index is permutated to minimize the least-square error of the two perimeters (Fig. 1d). This routine orientates the two perimeters and provides the displacement vectors application of Type-I boundary conditions in the finite element formulation. A Delaunay triangulation of the subject domain is automatically created[2], preserving the permutated perimeter order for application of the boundary conditions (Fig 2a). A linear-elastic finite element formulation is applied to the domain with Type-I displacements based on the least-square perimeter rotation. Generally, the displacement vectors exceed the linearly elastic range. Consequently, the displacements are applied incrementally which requires reformulation of the elastic matrix (Fig. 2b-d). However, the mesh topology remains constant and the process is completely automatic and rapid. When the finite element mesh motion terminates, each pixel within the subject space has a one-to-one mapping with the atlas space (Fig. 3).

a) b) c)


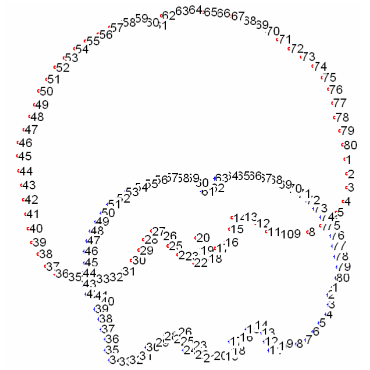
d)


Figure 1: Original gray scale images and overlapped outlines: a) gray scale b) masks c) outlines d) renumbered outlines

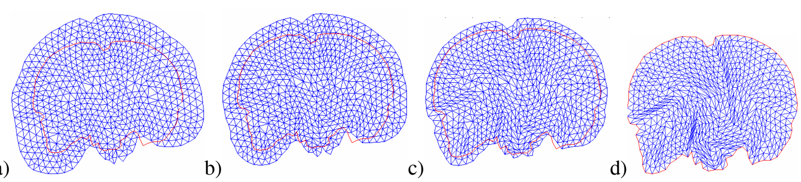
a) b) c) d)


Figure 2: Atlas (red) and subject mesh (blue) in a FEM application of 30 iterations:
a) iteration 1; b) iteration 10; c) iteration 20 d) iteration 30

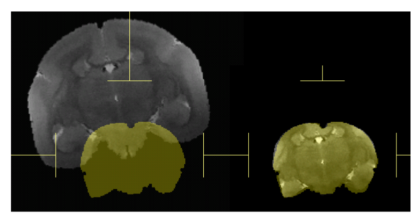


Figure 3: Registered cropped images

Results

This elastic registration method using a finite element geometric model was tested on MR image volumes with in-plane resolutions of 256x256. The reference volume was also an MR image, i.e. intramodality. The process is performed on a slice by slice basis. Results showed the outlines well mapped and subjects registered to the atlas in both shape and location. Figure 3 shows a representative cropped subject superimposed on the colored cropped reference. On the right the subject is superimposed on the atlas.

Conclusion and Future Work

This work verified that mapping outline indices is a reliable approach for finding FEM boundary conditions. It does not require user defined landmarks. Future work will consider tissue properties within the elastic formulation, perhaps based upon intensity, to enhance the process.

References:

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2. Sullivan, J.M., Jr., and Q.Y. Zhang, "Adaptive Mesh Generation Using a Normal Offsetting Technique", Finite Elements in Analysis and Design, 25, No.2, pgs. 275-295, (1997).

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