MR Image Guided 3D Registration and Mesh Generation for Brain Vasculature Model

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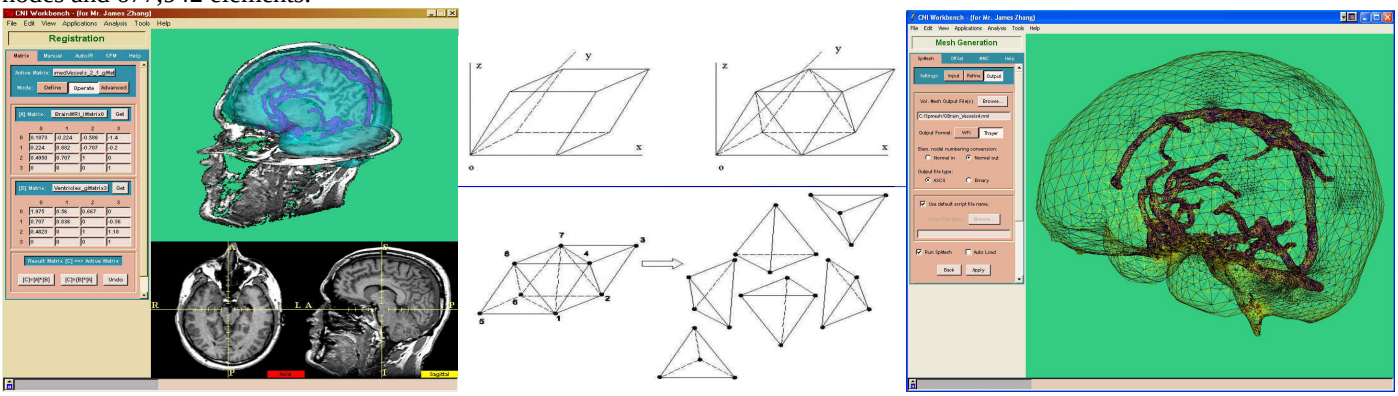
Introduction: An accurate 3D mesh model of brain vasculature is fundamental for analysis and treatment simulation. Computational model preparation is often considered a significant bottleneck in digital biological simulations. Generally the raw data of patient brains come from MRI datasets. A robust approach of 3D mesh generation guided by the MR brain image is introduced to generate vasculature models. The topologic relationship of the brain anatomy is extracted from MR images through an interactive segmentation process. It incorporates interactive ROI routines, semi-automated and automated segmentation algorithms with necessary user intervention. Atlases are fundamental to brain image analyses and serve as standardized templates on which other brain maps can be overlaid, for comparisons and integrations. Transforming MR intensity-based images onto a segmented 3D brain atlas mitigates subject-specific shape variations and allows subsequent comparisons of brain functions between multiple subjects.[1] To accelerate the modeling process, intra- and inter-modality registrations are applied to align subject specific images with a brain atlas and surface geometry. This resultant surface mesh is the input for volume mesh generation. In this approach, an innovated deltahedral building block is adopted in the meshing process. It creates anatomically accurate biological models in high-quality tetrahedral elements.

Methods: An intuitive graphical user interface (GUI) was developed that integrated image segmentation, registration and mesh generation processes. At first, the brain anatomical structures are identified through segmentation processes. Various options can be selected for the process, from interactive to automated segmentation. The NURBS curve is supported to construct region profiles. Secondly, image registration is applied to align the subject-specific MRI dataset with brain atlas and template geometry. Automated Image Registration (AIR) has been integrated into the system for intra-modality, inter-subject registration.[2] The resultant affine transformation matrix is directly transferred to template geometry. A fiducial mark registration routine has been implemented for inter-modality registration. Finally, a volume mesh generator developed in the laboratory is used to create the mesh model.[3] The 3D mesh generator supports multiple material domains. It uses a deltahedral entity as the building block to flood the domain, which supports multiple level mesh refinement without significantly reducing the mesh quality.

Results: A brain surface model with vessels was extracted from a template MRI dataset. The surface mesh was registered to the subject MR scan of 256x256, 124 slices. The volume mesh generator was called with an initial mesh size of 9 mm. Four levels of auto-refinement were applied on the vessels. In following figures, the left one shows the registered surface mesh of the brain and vessels to the MRI dataset. The deltahedral building block, in the middle figure, displays the layout and break down pattern to form high quality tetrahedral elements. The right figure is the volume mesh. The tetrahedral mesh model was generated with 120,921 mesh nodes and 677,942 elements.



Conclusions: An anatomically accurate 3D mesh model is critical for analysis and treatment simulation. The model preparation time can be reduced significantly by coupling 3D mesh generation process with image and digital brain atlas registration. An intuitive GUI for segmentation and registration provided a means to fulfill this task. The deltahedral building block, multiple-material mesh generator preserved the brain region delineations with fidelity while producing a high quality volume mesh suitable for numerical computation.

References:

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