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ADAPTIVE MESH REFINEMENT FOR NON-RIGID REGISTRATION OF BRAIN MRI

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ABSTRACT

The objective of tumor resection during neurosurgery is to remove as much as possible of the tumor tissue with the minimum damage to the neighboring brain structures. This goal is complicated by intra-operative shift of the brain tissue: pre-operative images become inaccurate. Open Magnetic Resonance (MR) scanners facilitate low-quality image acquisition during the surgery. Non-rigid registration (NRR) is the image-processing operation, which aligns salient features of the pre-operative images with intra-operative data, and thus enables surgeons to benefit from the high-resolution information, otherwise unavailable. NRR method presented in [1] is a part of the image processing protocol under evaluation at Brigham and Women's Hospital (Boston, MA, USA). This method uses FEM biomechanical model of brain deformation for brain shift estimation, and requires tetrahedral model of brain. In our research we aim algorithmic and software development and improvement of mesh generation for this specific NRR approach.

Given pre- and intra-operative MR images of the patient's brain, sparse estimation of deformation can be computed at the selected salient points by using block matching (BM) [1]. BM is an iterative search which defines most likely deformation at a point based on image similarity. The estimation of deformation is sparse and contains outliers. Finite element model of brain deformation is used to regularize the deformation, and derive displacement at each point of the image. Biomechanical model of brain deformation is based on the linear mass-tensor model described in [2]. Brain shift is estimated iteratively by using the biomechanical model to approximate the deformation, and reject the BM "measurements" with the highest error relative to that approximation. Deformation at a mesh vertex is caused by the force proportional to all the displacements within that vertex cell complex. At each iteration, matches which have the highest error with respect to the displacement interpolated from the mesh vertices are discarded, and their contribution is removed from the vertex force calculation. The final dense deformation field is derived by interpolation after convergence.

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There are at least two rather conflicting requirements to the mesh for this application. First requirement is concerned with the distribution of salient points in the mesh. Ideally, each vertex cell complex [2] should contain roughly the same number of BM points [1]. This allows to achieve sub-voxel accuracy, and negate the influence of outliers. At the same time, we need to use *a posteriori* error analysis to refine the mesh according to the error distribution [3]. The refined mesh, however, will not necessarily obey the first requirement. Salient point distribution is guided by the local image structure and can be accounted for during the initial mesh construction, while the discretization error can only be estimated *a posteriori*.

The NRR method in the focus of our research has been evaluated on a number of clinical cases, and the improvement in image alignment as compared to rigid registration was established [1,4]. The reported results were collected using uniformly sized meshes, which do not take into account point distribution or *a posteriori* error estimation. Based on the existing validation studies, we observe that non-negligible registration error is present after NRR. The objective of our research is to understand the contribution of the mesh to that error, and establish whether the error can be further reduced by constructing the mesh which takes into account the requirements listed above.

We use *Tetgen*, state-of-the-art Delaunay mesh generator [5], and our own sizing functions to control mesh refinement in a way that meets different NRR requirements. We setup a framework which is used to validate the efficacy of a particular mesh using both the "ground truth" from data collected during past neurosurgeries (11 sets of image data with expert-identified anatomical landmarks, accuracy estimation is limited to the landmark points), or real images deformed by applying the known transformation. Our initial results show that we manage to get much closer to a uniform distribution of block matching points per cell as compared to non-refined mesh. However, this leads only to limited improvements in the accuracy of the NRR code. We need to study additional properties of the initial sparse displacement field as it is computed from the block matching algorithm. In addition our current work includes mesh refinement using *a posteriori* error estimation, and development of the quantitative metrics for comparing the results of NRR using different meshes.

We will present the details of construction for the mesh and sizing function from the image data, and report the quantitative results of evaluating mesh impact on registration accuracy. These results from real images and synthetic benchmarks will help us and the rest of Bioimaging and Visualization participants to identify new directions and solutions for the next generation of mesh generation technology for non-rigid registration codes.

REFERENCES

[1] O. Clatz, H.Delingette, I.-F.Talos, A.Golby, R.Kikinis, F.Jolesz, N.Ayache, and S.K.Warfield. "Robust non-rigid registration to capture brain shift from intra-operative MRI". *IEEE Trans. Med. Imag.*, Vol. **24**(11), pp.1417–27, 2005.

[2] H.Delingette and N.Ayache. *Soft tissue modeling for surgery simulation*, in Handbook of Numerical Analysis, Vol. **XII**, pp.453–550, Elsevier, 2004.

[3] O.C. Zienkiewicz and R.C. Taylor. *The finite element method*, 6th Edition, Vol. **I**, Elsevier, 2005.

[4] N.Archip, O.Clatz, S.Whalen, D.Kacher, A.Fedorov, A.Kot, N.Chrisochoides, F.Jolesz, A.Golby, P.M.Black and S.K.Warfield. "Non-rigid alignment of preoperative MRI, fMRI, and DT-MRI with intra-operative MRI for enhanced visualization and navigation in image-guided neurosurgery". *Neuroimage*, Vol. **35**(2), pp.609–24, 2007.

[5] H. Si. "On refinement of constrained Delaunay tetrahedralizations". In Proc. of the 15th International Meshing Roundtable, pp.509–528, 2006.

[2] The set of all elements incident to a vertex.