A Machine Learning Approach for Intraoperative Reconstruction of Soft Tissue

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For the purpose of minimally invasive surgery, the real-time reconstruction of a surgical region of interest (ROI) has always been desired by clinicians. By accurately capturing the deformation of the ROI during procedure, the gap can be bridged between the preplan and intraoperative execution of the surgery. While it is computationally expensive and technically difficult to reconstruct the ROI in real time directly from the imaging modalities, fiducial marker (FM) tracing has shown to be promising in facilitating such reconstruction process. The current investigation proposes a machine learning approach called artificial neural network (ANN) for FM based intraoperative ROI reconstruction.

The presented study advances in three major steps: (i) the creation of ground truth deformations of ROI (benchmark), (ii) the training process of the ANN, and (iii) the performance evaluation of the trained ANNs. The 3D model of a head-and-neck tumor is used as the ROI object in this study. During benchmark creation, the eigendecomposition of Laplace-Beltrami operator is employed for creating multiple smooth force fields on tumor surface, after which the deformation benchmarks are computed through physically based simulations. The benchmarks in training set and test set are created independently. During the ANN training phase, nine ANNs with 2 hidden layers are created with varying number of neurons in each hidden layer. These ANNs are trained with training set to learn a high dimensional mapping between the displacements of empirically selected FMs (input), and the overall deformation of the tumor (output). Finally, an independent test set is utilized for evaluating the reconstruction accuracy of the trained ANNs. The evaluation metrics are formulated as the mean and maximum surface offset between the ANN reconstructions and benchmarks.

After testing ANNs with the benchmarks in the test set, the reconstruction results are shown to be promising in terms of both mean and maximum surface offsets. Given 1 cm as the maximum surface displacement in benchmarks, the test results show that an ANN with 50-50-neuron layer structure is suffice for achieving sub-millimeter reconstruction accuracy, which is the typical resolution of interventional ultrasound. Despite the multiple hours' training time for each ANN, the reconstruction time of a single case takes less than 1s.

Overall, a framework for FM-based shape reconstruction using ANN is developed as a proof of concept. The high reconstruction accuracy and the fast reconstruction process potentially make this study clinically relevant.