Generation and Initialization of Stable 3D Mass-Spring-Models for the Segmentation of the Thyroid Cartilage

Jana Dornheim1, Lars Dornheim1, Bernhard Preim2, Ilka Hertel1, Gero Strauss3

1Otto-von-Guericke-Universität Magdeburg
2HNO-Universitätsklinikum Leipzig

Purpose

To support the preoperative planning of larynx tumor resections by a 3D visualization of the patient-specific anatomy and pathology, a segmentation of the larynx cartilage structures from 3D CT datasets is required. The inhomogeneous nature of these cartilages makes their segmentation a challenging task, for which neither simple edge-based techniques, nor gray value-based methods are appropriate.

We use a Stable 3D Mass-Spring Model (SMSM) of the thyroid cartilage to encapsulate shape knowledge into the segmentation process. We describe the generation of this deformable shape model from a sample segmentation. It consists of a surface submodel representing gradient information as well as an inner volumetric model representing the inner gray value of the target structure.

For initialization, this model is adapted elastically to a given patient’s dataset in order to serve as a good starting point for the local optimization.

Model Generation - Surface Submodel

The purpose of the surface submodel is to detect the gradient information determining the target structure’s contour in the image. It is generated from an isotropic sample segmentation in the following steps:

1) Iso surface creation via Marching Cubes
2) Surface simplification via Quadric Error Metrics
3) Conversion into an SMSM:
   - vertices —> mass points with gradient sensors
   - edges —> springs
   - faces —> faces

Model Generation - Volumetric Submodel

The purpose of the volumetric submodel is to detect gray value information determining the target structure’s interior.

1) Initial set of mass points: place a mass point at voxel of the sample segmentation.
2) Reduction of mass points by a relaxation process: Move each mass point to the center of mass of all its neighbouring mass points within a given radius r.
3) Connect each mass point to all neighbours within a given radius p

The surface submodel and the volumetric submodel are connected with each other by 1:1 connections (each mass point of the surface submodel is connected to ist closest neighbouring mass point in the volumetric submodel).

Model Initialization

Good initial adjustment of the model to the given patient dataset is needed to ensure a robust segmentation process.

Initialization methods adjusting only position, rotation or scaling of the model are insufficient due to anatomical and pathological shape variations of the target structure (Figure).

We therefore introduce an elastic landmark-based initialization technique:

1) 6 landmarks were specified for the thyroid cartilage (Figure).
2) In the model creation, the mass point at each landmark was marked as a key mass.
3) For each patient dataset, the user specifies the landmark positions.
4) The key masses are moved to the specified positions and fixed.
5) Model adaptation is started without sensor input (only internal forces active).
6) The model re-establishes its shape while adapting to the landmarks (Figure).

Model adaptation times were 0.5 - 1.5 minutes for the elastic initialization and 2 - 4 minutes for the final segmentation process (on a standard PC). The interaction for specifying the 6 landmarks took up to 10 seconds for an anatomically knowledgeable user.

No significant loss of segmentation quality could be found in the cases of a pathologically deformed or destroyed larynx.

Evaluation

12 CT datasets of the neck were available for evaluation. In 3 datasets, the larynx was partially destroyed or displaced by a tumor. On all 12 datasets, a ground truth segmentation was given by a radiologist.

We first compared our elastic initialization technique to pure position and scale initialization. Thereto, the distance to ground truth was calculated for all initialized models (Table 1).

Model adaptation times were 0.5 - 1.5 minutes for the elastic initialization and 2 - 4 minutes for the final segmentation process (on a standard PC). The interaction for specifying the 6 landmarks took up to 10 seconds for an anatomically knowledgeable user.

No significant loss of segmentation quality could be found in the cases of a pathologically deformed or destroyed larynx.

Conclusions

We generated and adapted a deformable 3D model (SMSM) for the segmentation of the inhomogeneous and complex-shaped thyroid cartilage. By our elastic landmark-based initialization method, the prototypically generated model can be adapted to patient-specific shape variations occurring in new datasets. In contrast to statistical shape models, this method is not limited to a pre-learned range of shape variations, but can be used for pathologically deformed target structures as well.

Comparsed with the previous manual or Live Wire segmentation of this cartilage, the model-based method offers a drastic reduction of interaction effort. Already now, the model can be used at least as a presegmentation of the cartilage, which needs only be corrected at 2-3 positions by the user.

This project is being supported by the DFG (Deutsche Forschungsgemeinschaft, SPP 1124)

Visualization Group
Jana.dornheim@isg.cs.uni-magdeburg.de (+49-391) 67-12759
Department of Simulation and Graphics