

Pre-operative Segmentation of CT and MRI data for the Planning of Neck Dissections

Jana Dornheim¹, Jeanette Cordes¹, Bernhard Preim¹, Ilka Hertel², and Gero Strauss²

¹ Otto-von-Guericke University,
Department of Simulation and Graphics,
Postfach 4120,

D-39106 Magdeburg, Germany
{Jana.Dornheim, Cordes, Preim}@isg.cs.uni-magdeburg.de
<http://isgwww.cs.uni-magdeburg.de/cv/>

² Hals-Nasen-Ohren-Universitätsklinik,
Universitätsklinikum Leipzig,
Liebigstr. 18a,
D-04103 Leipzig, Germany
{Ilka.Hertel, Gero.Strauss}@medizin.uni-leipzig.de

Abstract. Therapeutically relevant anatomical structures of the neck are to be segmented from CT and MRI data for visualizing the patient-specific pathology in 3D to support preoperative surgical decisions.

In this paper, we examine the appropriateness of elementary segmentation techniques based on gray values and contour information for segmenting structures in the neck region. Region Growing, Interactive Watershed Transformation and Live-Wire are employed for segmentation. It is also examined, which of these method can be automated. The integration of these segmentation techniques into the software assistant *NeckVision* is described.

1 Introduction

Neck Dissections are performed in the context of tumor affections in the head- and neck region, in order to remove lymph node metastases. The chosen surgical procedure has a great impact on both the patient's life expectancy and further life quality and is determined by the existance of enlarged (i.e. potentially metastatic) lymph nodes and their infiltration in neighbouring muscles, nerves and blood vessels.

Today, the preoperative planning of a Neck Dissection is performed on the basis of 2D slice images resulting from CT or MRI scans without dedicated support. The surgical strategy often has to be changed intraoperatively and neck dissections are sometimes cancelled, because inoperability was only discovered during the intervention.

In order to facilitate more reliable preoperative decisions w.r.t. to resectability and the surgery strategy in advance, the number and size of enlarged lymph

nodes, as well as their position w.r.t. risk structures, shall be visualized preoperatively for the surgeon in 3D. This requires a preoperative segmentation of the primary tumors, as well as the adjacent risk structures and other structures which serve for spatial orientation. According to our surgical partners, the following structures are generally considered during the preoperative planning of a Neck Dissection:

- Primary tumor (size, location)
- All lymph nodes larger than 1cm (number, location, size)
- Blood vessels of the neck, in particular the v. jugularis and a. carotis (risk structures)
- Muscles, in particular the m. sternocleidomastoideus (risk structure)
- Bones, in particular the vertebrae, mandible and clavicle (context structures)
- Pharynx (context structure)

Apart from these structures, sometimes the depiction of the larynx (cricoid cartilage, thyroid cartilage, epiglottis), salivary glands (submandible and parotid glands), thyroid gland, esophagus and additional muscles and nerves (m. omohyoideus, n. vagus, n. hypoglossus, n. accessorius) are considered, depending on the individual pathological situation.

For tumor staging, measurements are required, which also assume a preceding segmentation of the patient data. Typical measuring tasks include the distance of lymph nodes to risk structures, as well as the extent of pathological structures.

Image analysis in the neck region is difficult since many structures with similar intensity values (in CT and MRI data) are located in a small space (see Fig. 1). We evaluate rather simple segmentation methods and combine them such that results from previous steps can be employed for later more demanding segmentation steps.

2 State of the Art

For the segmentation of blood vessels, bones and air-filled organs, a variety of segmentation methods have already been developed, e.g. variants of region growing [1] or the Watershed Transformation. Semiautomatic approaches have been tested for the segmentation of lymph nodes in CT datasets, e.g. with Fast Marching [2].

For the automatic detection of neck lymph nodes and for the segmentation of specific anatomical structures of the neck, like the larynx, salivary and thyroid glands, and the sternocleidomastoid muscle, no solution exists so far.

3 Material

For the examination, 12 CT and 4 MRI datasets of the neck were available. 13 of these datasets contained a tumor in the neck region, with suspicion of neck lymph

node metastases. The slice distance of the datasets varied significantly (0.7 - 5 mm), 2 datasets bore motion artifacts. The image analysis was performed using the image analysis and visualization platform MeVisLab (www.mevislab.de).

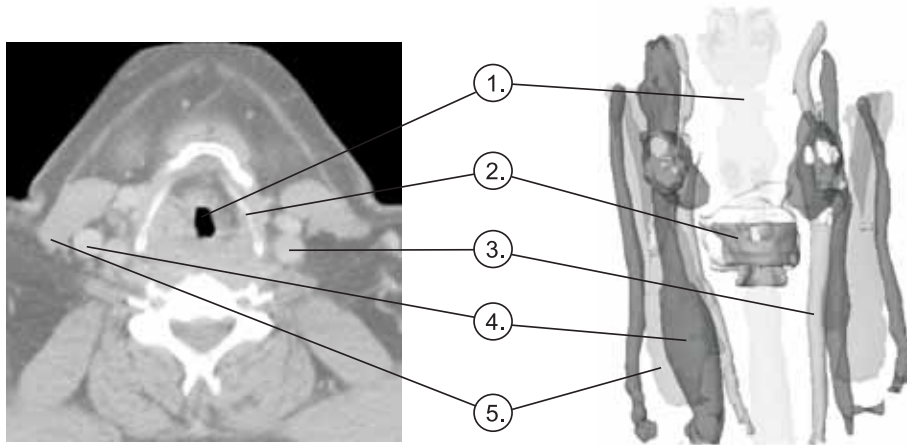


Fig. 1. CT dataset of the neck (left) and 3D visualization of the segmentation results (right). 1) Pharynx, 2) Larynx (thyroid cartilage), 3) A. carotis communis, 4) V. jugularis interna, 5) M. sternocleidomastoideus

4 Methods

Elementary segmentation methods based on gray value and contour information were tested for the segmentation of the above-mentioned anatomical structures. They are ordered by their degree of interactivity, LiveWire being the most interaction-demanding technique.

Threshold Interval: Thresholding in connection with a connected component analysis was evaluated for air-filled structures.

Region Growing: The classical Region Growing with adjustable gray value interval and relative homogeneity parameter was examined.

Interactive Watershed Transformation: Here, the interactive watershed transformation of [3] was used, which allows for placing include and exclude markers in the dataset.

Live Wire: We used the extended Live Wire Algorithm presented by [6], with a feature to automatically adapt the cost function to the current dataset. For 3d segmentation, the contours can be interpolated between slices, whereby the interpolated contours are optimized again according to the current cost function.

Criteria for the evaluation of the examined techniques were a good quality of the segmentation results combined with small time and interaction effort. Besides, the ability for automation was important.

Additionally, we examined, how well enlarged lymph nodes, the primary tumor and therapeutically relevant nerves could be segmented. Image analysis was performed as a service for the clinical partner in the framework of a research project. The segmentation results were verified by a radiologist. The data exchange was accomplished via the world wide web, with defined information on diagnosis and the clinical problem as starting point for the image analysis, and standardized images and animation sequences for the visualization of the results.

4.1 Segmentation of air-filled anatomical structures

The segmentation of the trachea and the pharynx is accomplished with intensity-based thresholding (-1024 ... -300 HU). It is guided by a seedvoxel in the glottis and comprises a component of voxels connected to this seedvoxel (see Fig. 2).

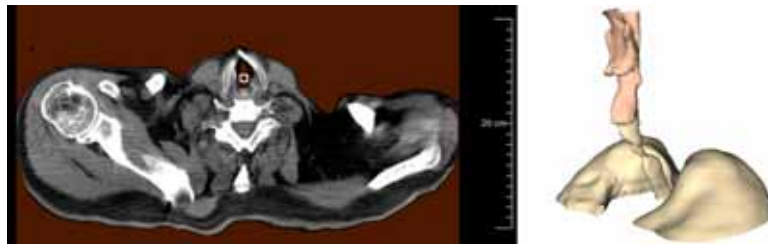


Fig. 2. With a single seedpoint, the trachea and pharynx are segmented from CT neck data.

4.2 Segmentation of the bones

The segmentation of the bones could generally be performed with a simple Region Growing with up to 15 markers, in cases where not all the bones in the dataset were connected with each-other.

In datasets with a contrast agent, the blood vessels often had a similar gray value range with the bones and were difficult to separate from them. This problem could be reduced by a fixed order of segmentation: Prior to the bone segmentation, the blood vessels were segmented using an interactive watershed transformation according to [3] (see Fig. 3). 10 to 30 exclude markers were necessary. The following parameters turned out to be optimal: preflooding height 111, mask threshold 1172). For subsequent segmentation tasks the vessel segmentation was afterwards subtracted from the dataset).

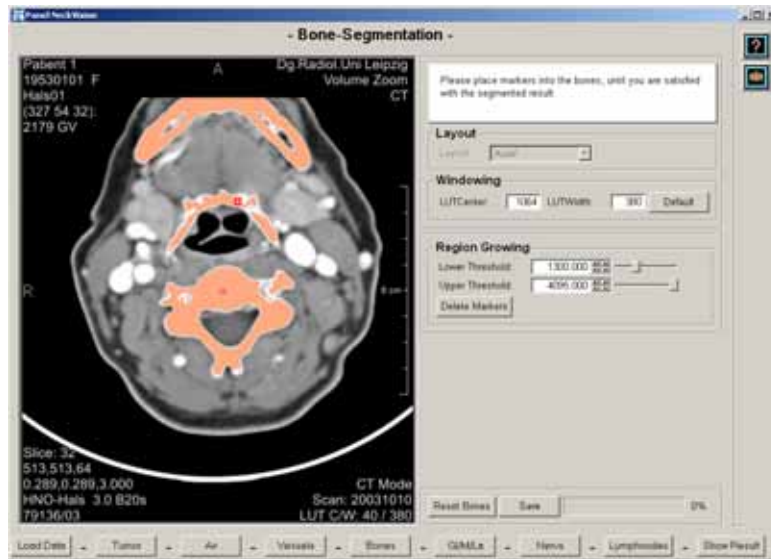


Fig. 3. Segmentation of bones. In the bottom part, the order of segmentation in *Neck-Vision* is indicated.

4.3 Segmentation of soft tissue structures

For all other structures, the segmentation turned out to be difficult. Watershed transformation as well as Region Growing led to strong leaking with all soft tissue structures, which could only be prevented by time-expensive setting of barriers. With the used Live-Wire Algorithm however, the muscles, salivary glands, the larynx and the thyroid gland could be segmented successfully. At weak edges, more seed points were placed or parts of the contour were manually defined (a function key supports a fast switch between Live Wire and manual segmentation).

4.4 Lymph node segmentation

Also with the lymph nodes, the order of segmentation proved to be critical. The leaking in other structures could be significantly reduced by first removing all pre-segmented structures from the dataset. By applying a region growing with a narrow homogeneity parameter and a subsequent dilation, a mask could be generated around a lymph node, which further limited the leaking. Isolated, convex lymph nodes could be segmented with one click this way. For lymph nodes touching or infiltrating blood vessels and muscles, however, and with strongly concave lymph nodes, a manual segmentation was still necessary.



Fig. 4. Segmentation of bones. In the bottom part, the order of segmentation in *NeckVision* is indicated.

5 Software Assistant NeckVision

The above-described segmentation techniques were integrated into *NeckVision*. This software assistant is implemented based on the image-analysis and visualization platform MeVisLab [7]. The user interface is designed for clinical use (recall Fig. 3 and 4). The segmentation with *NeckVision* follows a fixed order, which has been derived from the above-described observations.

6 Results

All datasets could be segmented successfully. The segmentation time effort varied between 50 and 150 minutes per dataset, depending on the data quality and number of segmentation target structures. Table 1 shows the time needed for the segmentation, measured for 16 datasets and one user. The segmentation of the MRI datasets demanded significantly more interaction than the segmentation of the CT datasets.

7 Discussion

The quality of the segmentation results was referred to as satisfactory and better by our surgical partners. The segmentation results have been used as input for a system with dedicated 3d visualization techniques for ENT surgery [5]. As an

Table 1. Segmentation times of the particular anatomical structures (in minutes).

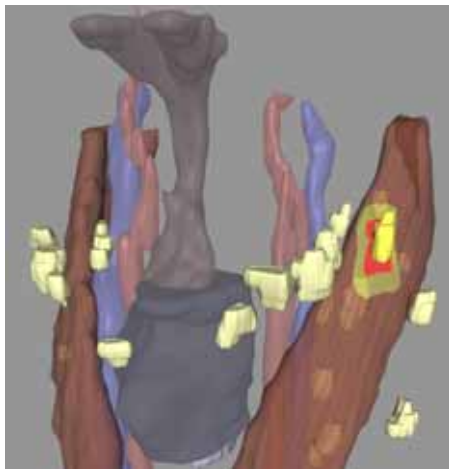
| Organ | Average | Minimum | Maximum | Std. Dev. |
|------------------------------------|---------|---------|---------|-----------|
| Blood vessels | 23,2 | 10 | 40 | 7,11 |
| Bones | 4,8 | 2 | 5 | 0,77 |
| M. sternocleidomastoideus | 18,1 | 10 | 30 | 6,04 |
| Salivary Glands | 19,7 | 18 | 20 | 0,75 |
| Pharynx | 3,9 | 2 | 5 | 1,24 |
| Lymph nodes (in 13 of 16 datasets) | 31,7 | 7 | 80 | 18,85 |
| Sum | 89,9 | 50 | 150 | 24,67 |

example, the visualization of lymph nodes indicates their size and critical structures, such as vascular structures are color-coded with respect to distances to enlarged (probably malignant lymph nodes). Fig. 5 shows visualizations generated by the ENT intervention planner. Visualization parameters, such as colors and opacity have been standardized to support efficient surgery planning.

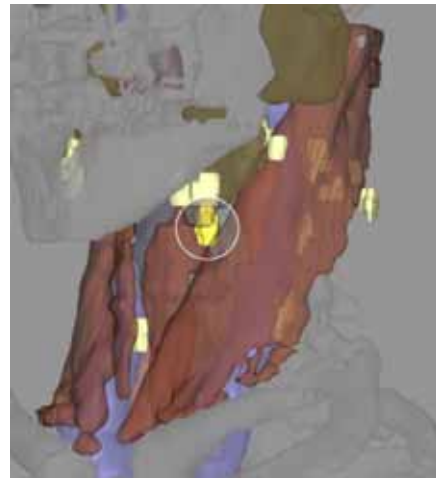
In order to transfer the methods to clinical practice however, the time and interaction effort for the segmentation must be reduced significantly. The goal is to demand not more than 10 minutes of interaction from the user, after that, only automatic calculations may still take place. To achieve further automation, the use of model-based segmentation techniques with the use of shape knowledge seems essential. For example, the segmentation of the blood vessels and long muscles might be significantly improved this way. As a first step, we developed a 3d mass spring model for the segmentation of the thyroid cartilage [4]. We decided to postpone the clinical evaluation of NeckVision until model-based techniques are incorporated.

The automatic detection and segmentation of enlarged lymph nodes is also of great importance for the planning of Neck Dissections. In particular, a reliable detection of therapy-relevant lymph nodes ($> 1cm$) is strongly desirable. The segmentation described here is an important prerequisite for lymph node detection. On the one hand, segmented structures can be excluded from lymph node detection. On the other hand, lymph nodes appear in certain distances from vascular structures and muscles. Therefore expectancy maps can be generated which comprise for a particular patient the regions where lymph nodes are likely to occur.

For surgery planning the visualization of the above-mentioned nerves is also essential. This is difficult, as the nerves are only visible in CT images in very few locations, due to their small diameter and low contrast. Therefore, their segmentation always had to be performed manually in these locations. In-between the identified locations, the course of the nerve was interpolated linearly. The uncertainty connected with this seems acceptable from a clinical point of view.



(a) Distances to an enlarged lymph node are color-coded on M. sternocleidomastoideus.



(b) Cutaway-illustration to explore lymph nodes. A cylindrical region is generated and rendered transparent to reveal the selected lymph node.

Fig. 5. Visualization of segmentation results for surgery planning.

References

1. Selle, D., Preim, B., Schenk, A., Peitgen, H.O.: Analysis of vasculature for liver surgical planning. In: IEEE Transactions on Medical Imaging, Vol. 21 (2002), pp. 1344-1357.
2. Yan, J., Zhuang, T., Zhao, B., Schwartz, L.H.: Lymph node segmentation from CT images using fast marching method. In: Computerized Medical Imaging and Graphics, Vol. 28 (2004), pp. 33-38
3. Hahn, H.K., Peitgen, H.O.: IWT - Interactive Watershed Transform: A hierarchical method for efficient interactive and automated segmentation of multidimensional grayscale images. In: Proc. SPIE Medical Imaging 2003, Volume 5032, San Diego, SPIE(2003)
4. Dornheim, J., Dornheim, L., Preim, B., Tönnies, K.D., Hertel, I., Strauss, G.: Stable 3D Mass-Spring Models for the Segmentation of the Thyroid Cartilage. Technical Report, Computer Science Department, Otto-von-Guericke University of Magdeburg.
5. Krüger, A., Tietjen, C., Hintze, J., Preim, B., Hertel, I., Strauss, G.: Interactive Visualization for Neck Dissection Planning. In IEEE/Eurographics Symposium on Visualization (EuroVis), pages 295-302, 2005.
6. Schenk, A., Prause, G.P.M., Peitgen, H.O.: Efficient semiautomatic segmentation of 3d objects in medical images. In: Medical Image Computing and Computer-Assisted Intervention - MICCAI 2000. pp. 186-195
7. Hahn, H.K., Link, F., Peitgen, H.O.: Concepts for rapid application prototyping in medical image analysis and visualization. In: Schulze, Schlechtweg, Hinz (eds.): Proc. Simulation und Visualisierung 2003, Magdeburg, Germany.