A Fast and Accurate Approach for the Segmentation of the Paranasal Sinus

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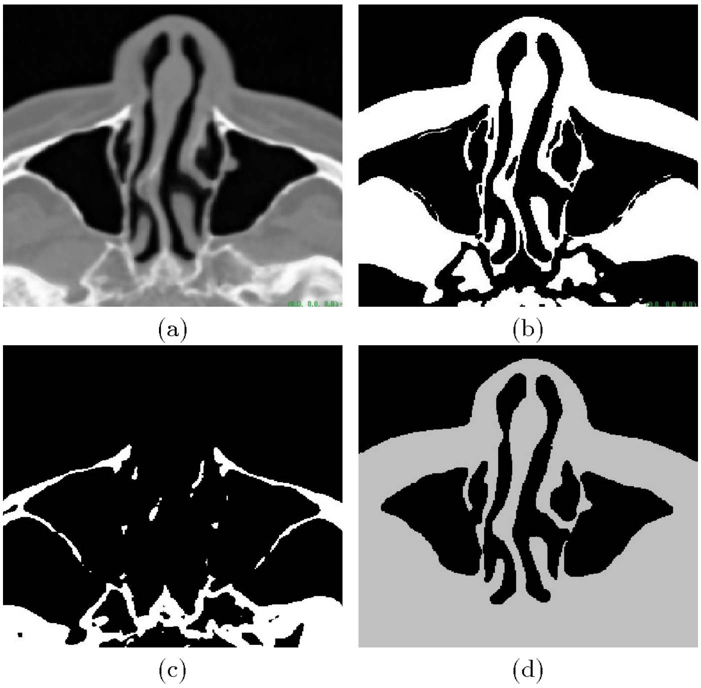
Abstract. Recently, functional endoscopic sinus surgery became state of the art in the surgical treatment of endonasal pathology. For a more accurate access planning including 3D measures of the cavity, especially in complex cases of tumor diseases, segmentation of the paranasal sinus can be very useful. Unfortunately, this structure is quite complicated and difficult to segment. In our contribution, we propose a semi-automatic segmentation pipeline that significantly reduces the total processing time and the required interaction.

1 Introduction and Related Work

Minimally-invasive interventions of the paranasal sinus are frequent surgical procedures. While in many cases an extensive pre-operative intervention planning is not really necessary, it becomes desirable in complicated patient cases, and is currently done based on the inspection of the acquired CT data of the paranasal sinus. For a more accurate access planning including 3D measures of the cavity, especially in complex cases of tumor diseases, segmentation of the paranasal sinus can be very useful. Moreover, a computer aided system that allows the determination of the volume of the nasofrontal duct and the determination if the duct is open or not may supply future rhinologists with valuable diagnostic information for patient treatment. In addition, the segmentation of the endonasal cavities can be regarded as an extremely useful technology in future approaches using mechatronic assisted, navigation-controlled procedures in endonasal sinus surgery.

Unfortunately, this structure of the paranasal sinus is quite complicated and difficult to segment, so that contour-based segmentation approaches like the live-wire [1] are very tedious and time-consuming due to the required per-slice user-interaction. Therefore, some methods have been proposed to avoid interactively computing contours at every slice, examples are interpolation [2] and adaptive propagation [3]. However, such methods have limited usability when the targeted

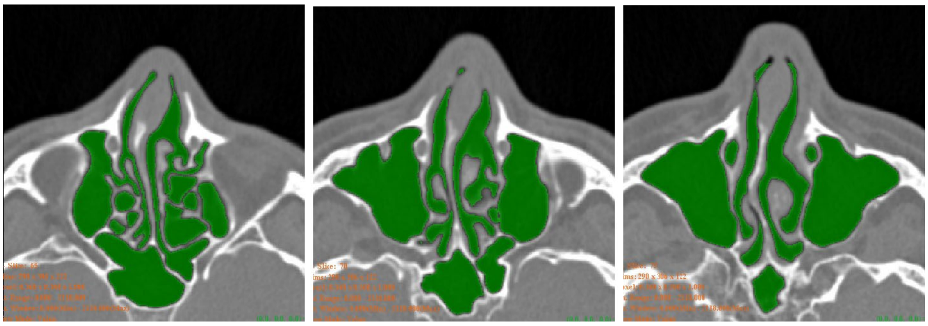
Fig. 1. Overview of the segmentation process: (a) a slice from the preprocessed volume, (b) marked soft tissue (c) segmented bones, (d). segmentation of the paranasal sinus, including leaking regions.



organ (like the paranasal sinus) exhibits rapid shape changes between slices. Slice-oriented methods for segmenting the antrum boundary of the paranasal sinus still include much interaction[4, 5]. For a faster segmentation, 3D-oriented approaches are usually preferable. Region Growing (RG) techniques are among the most common approaches. Seeded Region Growing presented in [6] and its improved version [7] both exploited the conventional RG algorithm, where the criteria of similarity of pixels is applied. They start with a small number of user-chosen seeds and group them into regions. In [8], the applicability of virtual endoscopy in the region of the nose and paranasal sinuses was evaluated on the basis of volume-rendered spiral CT data.

Due to the mentioned complex anatomical structure of the Paranasal sinus, which renders an automatic segmentation procedure virtually impossible, we are aiming at segmentation procedure that requires as little as possible user interaction in order to reduce expensive clinician time. Our approach is mainly based on numerous data enhancement and segmentation filters of ITK [9]. We also included a viewer for the exploration, visual evaluation, and comparison of different segmentation results. Furthermore, we included a post-processing tool for further correction and refinement of the segmentation, mainly to simplify the

Fig. 2. Three slices from a segmented paranasal sinus.



removal of incorrectly segmented regions. In comparison to other methods, our approach reduces the total processing time to approximately 10min, and even more important, the interaction time to few minutes.

2 Segmentation Method

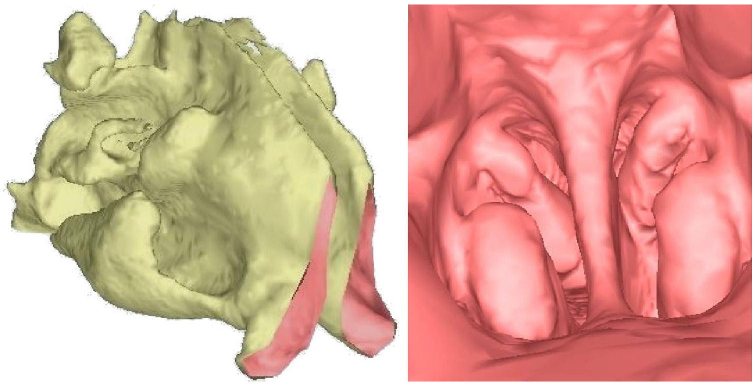
The main part of our segmentation process is based on the adaptation of our mastoid segmentation procedure [10]. The approach is based on multi-slice CT scans of the head, focusing on the paranasal sinus region. This region contains several membrane-like structures, Affected by partial volume effects, which renders the segmentation as a non-trivial process.

After defining the region of interest, we begin with a preprocessing step in which the contrast of the input dataset is first enhanced. Poor contrasts are usually caused by existing metal parts (tooth implants or other implantats) that appear in extremely high intensities relative to the actual anatomical structures. Contrast enhancement is performed using *windowing*. Datasets are then denoised by an *edge-preserving* smoothing filter (e.g. Gradient Anisotropic Diffusion). The use of such smoothing is preferable, since traditional blurring approaches tend to resolve thin, sharp structures that are important in our case.

A first-phase segmentation is performed using 3D region growing that successively merges neighboring voxel of a seed voxel(s) that meet a specified intensity threshold criterion. We first apply this region growing process to highlight the soft tissue (medium Hounsfield intensities) and mark bone structures accordingly (Figure 1b and c respectively). This will ensure that these structure are maintained, when we segment the sinus. Finally the paranasal hull is extracted (Figure 1d). By examining the data histogram for intensity ranges, where the frequency distribution abruptly changes, threshold values needed for the region growing filters are estimated.

The first-phase segmentation usually leaks into parts that do not belong to the sinus (due to the nature of the region-growing filters). For example, it leaks into the mouth and out of the nose holes. This is shown in Figure 1d, where all the black region, including the outside part, was included by the segmentation.

Fig. 3. (a) RAO-view of a 3D reconstruction of the air space of a paranasal sinus, (b) virtual endoscopy of Rhinoscopia Posterior.



(a) (b)

To overcome this problem, we use a post-processing tool that detect the leakage regions by generating a path (centerline) from a source point in the sinus and a destination point in the leaked region. An oblique cutting plan is then placed at the location where the cross section across the centerline reveals the narrowest connection.

3 Results

We tested our system by processing several patient datasets. The segmentation results of our procedure were evaluated visually using a special slice-oriented viewer that allows the viewing, visual evaluation, and comparison of different segmentation results by aligning slices of the data volume with multiple semi-transparent, colored slices (overlays) of segmented data. Some results of the segmentation are shown in Figure 2.

Three-dimensional reconstructions of the segmentation results were helpful for several diagnostic purposes; for example, the determination of the volume of the nasofrontal duct and determination if the duct is open. In Figure 3a, a RAO-view (Right Anterior Oblique) of a 3D reconstruction, where the CT was taken during a severe inflammation. Note that the nasofrontal duct is not included by the segmentation, due to the blockage. We also provided an endoscopy view, which allows for a flexible walk-through of the sinus cavities. A snapshot of the virtual endoscopy of Rhinoscopia Posterior is shown in Figure 3b.

Applied on an extracted region of interest (about 250x250x200), the segmentation process requires one to three minutes on a 1.2 GHz AMD PC. However, complex correction/refinement sessions involve more user interaction. For the dataset that we processed, the total time ranged between five and ten minutes.

4 Discussion

In this contribution, we propose an efficient procedure for the segmentation of the paranasal sinus that requires only very limited user-interaction and reduces the total processing time significantly. A complete segmentation session, including possible refinement/correction, ranges between five and ten minutes.

In addition to some diagnostic purposes, this segmentation is applicable for several clinical application such as computer aided or navigated and robotic assisted surgery of the paranasal sinus. Based on this segmentation technique, we provide a paranasal visualization tool with a 3D overview and endoscopic view.

Acknowledgment

This work has been supported by the German Academic Exchange Service (DAAD) and the DFG focus program 1124 on "Medical Navigation and Robotics".

References

1. Mortensen E, Barret W. Intelligent Scissors for Image Composition. In: Procs ACM Siggraph 1995; 1995. p. 191–198.
2. Schenk A, Prause G, Peitgen HO. Local Cost Computation for Efficient Segmentation of 3D Objects with LiveWire. In: Procs SPIE Medical Imaging, Vol 4322; 2001. p. 1357–1364.
3. Salah Z, Orman J, Bartz D. Live-Wire Revisited. In: Procs BVM; 2005. (to appear).
4. Apelt D, Preim B, Hahn H, et al. Bildanalyse und Visualisierung für die Planung von Nasennebenhöhlen-Operationen. In: Procs BVM; 2004. p. 194–198.
5. Hertel I, Strauss G, Apelt D, et al. Surgical Segmentation for Preoperative Planning in Paranasal Sinus Surgery. In: Procs CARS; 2004.
6. Adams R, Bischof L. Seeded Region Growing. IEEE Trans on PAMI 1994;16(6):641–647.
7. Mehnert A, Jackway P. An Improved Seeded Region Growing Algorithm. Pattern Recognition Letters 1997;18(10):1065–1071.
8. Rogalla P, Nischwitz A, Gottschalk S, et al. Virtual Endoscopy of the Nose and Paranasal Sinuses. European Radiology 1998;8(6):946–950.
9. ITK. National Library of Medicine, Insight Segmentation and Registration Toolkit (ITK). [online] Available: http://www.itk.org; Rel. 1.8.
10. Salah Z, Bartz D, Schwaderer E, et al. Segmenting the Mastoid: Allocating Space in the Head for a Hearing Aid Implantation. In: Procs BVM; 2004. p. 45–49.