Segmenting the Mastoid: Allocating Space in the Head for a Hearing Aid Implantation

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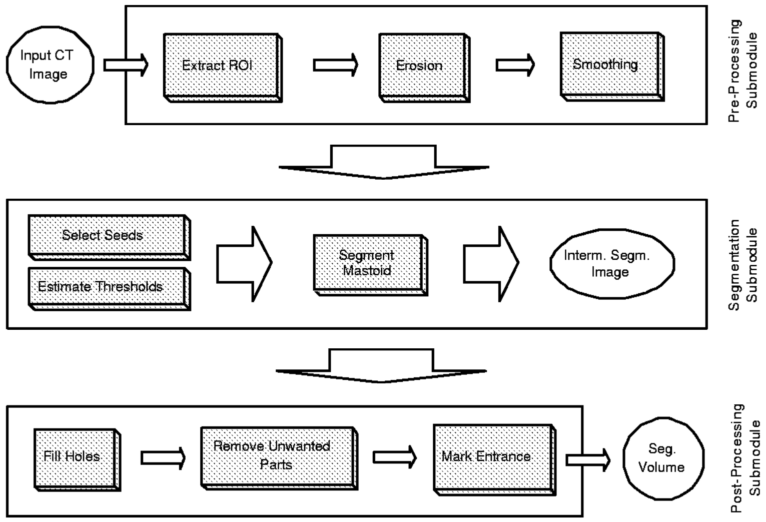
Abstract. We present a procedure for the segmentation of the mastoid - a sponge-like bone structure behind the middle ear - from CT Images. This segmentation is a first pre-operative step for a robot-supported hearing aid implantation. Up to now, the mastoid is milled out by an ENT surgeon to allocate space for the hearing aid. This tedious milling process of the mastoid is intended to be performed by a robot to reduce the required time and improve the accuracy.

1 Introduction and Related Work

Segmentation of 3D medical images plays a vital role in many medical procedures, where it serves in most cases as a preparing step for further preoperative analysis and planning. In our research, we introduced a procedure for segmenting the mastoid. For this purpose, we investigated several segmentation methods provided by ITK (NLM Insight Registration and Segmentation Toolkit) and commonly used in segmentation.

Level-set-based segmentation filters worked well for the segmentation of various organs. For example, a level-set based approach was used in [1] to segment the carotid artery in MR angiograms in order to determine the degree of stenosis. However, the inhomogenous sponge-like nature of the mastoid blocked a successful application. Furthermore, level-set methods [2,3] are significantly slower than the finally adopted region-growing method and require parameter tuning which contradicts our project goals. Other mostly automatic segmentation methods did also not succeed segmenting the mastoid, while semi-automatic filters like LifeWire [4] usually require too much per-slice user-interaction until the result is achieved. Region Growing (RG) techniques are among the most common segmentation approaches. Seeded Region Growing (SRG) presented in [5] and its improved version presented in [6] 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. A 3D region growing technique called Voxel Grow has been also introduced in [7].

Fig. 1. System Block Diagram



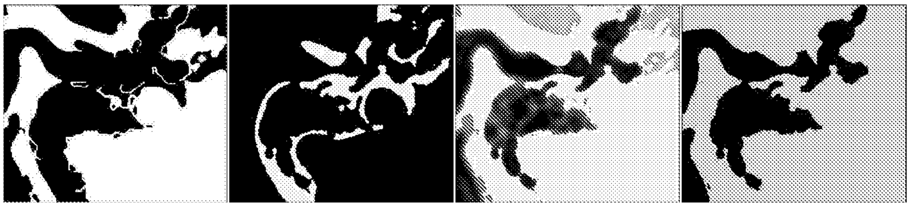
The complex anatomical structure of the mastoid renders an automatic segmentation procedure as impractical. Henceforth, we are aiming at a segmentation procedure that requires as little as possible user interaction in order to release expensive physician time. Our approach is based on numerous data enhancement and segmentation filters of ITK. We also developed a viewer for the exploration of the volume datasets. In particular, it allows the viewing, visual evaluation, and comparison of different segmentation results. Furthermore, we included a post-processing editor for further processing of the segmentation result, mainly to simplify the removal of incorrectly segmented regions.

2 Methods

Our segmentation pipeline is based on a multi-slice CT scan of the head, focusing on the ear region. To minimize user interaction as much as possible, we used 3D implementations of the processing filters and avoided the use of slice-based filters where per-slice interaction is required. Our segmentation procedure, depicted in Figure 1, includes three major step:

1. Preprocessing: In order to avoid long, possibly unnecessary computing, we begin by extracting the region of interest out of the input image and apply all further processing on it, rather than on the whole image. This preprocessing step prepares the input image into an appropriate form for segmentation step. In particular, it vacates the mastoid from the sponge-like structures that degrade the success of the segmentation filters severely. These thin bone structures are removed using an improved implementation of morphological erosion [8]. Remaining structures are resolved by filtering the image with recursive Gaussian smoothing [9].

Fig. 2. Segmentation Process (left to right): Grey Soft Tissue, Bones, Temporary Image, and Preliminary Mastoid Segmentation (black)



2. Segmentation: This step aims at extracting the mastoid hull. We implemented this step using intensity-threshold based region growing. First, we apply a region growing filter to segment the grey soft tissue region that surrounds most of the mastoid. A second filter is used to segment the bones. We combine the results of these two filters together with the original input image to produce a temporary image, from which a final region growing filter extracts the mastoid. This sequence is outlined in Figure 2. Each of the three filters requires two threshold values as input. These values can be entered interactively, but the system can also automatically guess appropriate values by examining the histogram of the smoothed image computed in the previous step.

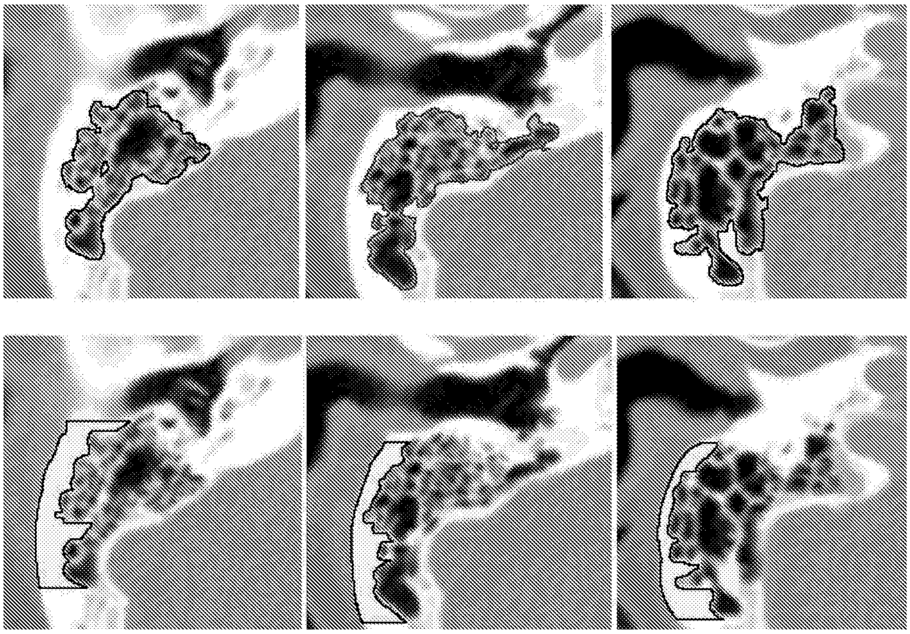
Unfortunately, the mastoid segmentation filter may still leak out through holes, hence false regions may be segmented. Since we do not have pre-knowledge about the size as well as the locations of these holes, we decided to permit this leaking and post-process it later.

3. Post-Processing: This steps aims at refining the result of the previous step so that we end up with a clean segmentation of the mastoid. Three main operations are performed in this step:

1. the (possibly existing) internal holes (not-segmented, closed 3D regions within the segmentation) are removed by inverse region growing.
2. unwanted parts are clipped from the segmentation. For this purpose, we developed a semi-automatic editor that detects *connections* to the leaked regions and then removes unwanted parts.
3. an opening of the skull is selected as an entrance for the robot-driven milling process. This is done by marking all skull voxels that (from an out-to-in view) lead to the mastoid.

The second step is actually the most important, and is basically performed as follows: two voxels are selected by the user, one inside the mastoid and the other inside the object to be removed (the leaked region). We then find a path between these voxels in the form of an approximated centerline. Note that the path should go through the connection between the mastoid seed and the object seed. The position along this path where it passes through the narrowest location is located by generating cross sections across the path at equally spaced distances and finding the section that cuts the segmentation with smallest intersection. Finally, the user can accept this position or select an alternative. By placing a

Fig. 3. Segmented Mastoid(above), Realizing an entrance to the mastoid (below)



clipping plane, the unwanted part is removed. The whole procedure is applied for all parts that we wish to remove.

3 Results

The segmentation results of our procedure were evaluated visually using a viewer that we developed specially for this purpose. This viewer enables the viewing of medical images in a traditional, slice-oriented manner. We incorporated this viewer in our application to view intermediate as well as final results. Moreover, it allows the viewing, visual evaluation, and comparison of different segmentation results by aligning slices of the volume data with semitransparent overlays of segmented data.

The upper row of Figure 3 shows three slices from a segmented mastoid volume. The lower row shows the realized entrance to the mastoid through the skull.

The execution time of the preprocessing and segmentation steps for full size images (approximately hundred 512x512 slices) take approximately 200 seconds on a 1200 MHz AMD PC. However, this process requires only 40-50 seconds if applied on an extracted region of interest (e.g. 250x220x90). A complete post-processing session time varies, depending on the size of the volume and the complexity of the shape of the resulted segmented object, i.e. on the amount of required cutting. It ranges, however, between two and six minutes of required user-time, in contrast to the previously tedious manual segmentation that took between 20 and 40 minutes.

4 Discussion

The segmentation procedure that we presented is used for a robot-supported hearing aid implantation. As our top goal, we were able to reduce the previous segmentation time, in particular the required time for user-interaction. In the near future, the Department of Radiology will conduct a study on the effectiveness of the segmentation pipeline used by clinical personnel.

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