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Image Processing of Conventional Computer Tomography Images for Segmentation of the Human Cochlea

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Abstract. Against the background of increasing numbers of indications for Cochlea implants (CIs), there is an increasing need for a CI outcome prediction tool to assist the process of deciding on the best possible treatment solution for each individual patient prior to intervention. The hearing outcome depends on several features in cochlear structure, the influence of which is not entirely known as yet. In preparation for surgical planning a preoperative CT scan is recorded. The overall goal is the feature extraction and prediction of the hearing outcome only based on this conventional CT data. Therefore, the aim of our research work for this paper is the preprocessing of the conventional CT data and a following segmentation of the human cochlea. The great challenge is the very small size of the cochlea in combination with a fairly bad resolution. For a better distinction between cochlea and surrounding tissue, the data has to be rotated in a way the typical cochlea shape is observable. Afterwards, a segmentation can be performed which enables a feature detection. We can show the effectiveness of our method compared to results in literature which were based on CT data with a much higher resolution. A further study with a much larger amount of data is planned.

Keywords. Cochlea, computer tomography, hearing outcome, inner ear, feature extraction, segmentation

1. Introduction

In 2018, hearing loss was the fourth highest cause of disability in the world with an increasing number every year. This sensory disease has a high impact on quality of life and general functioning in the information and communication society and is affecting more than 17% of our population [1]. Depending on the degree of hearing loss, many affected people can be successfully fitted with hearing aids, but for a large population, hearing aids simply do not provide enough acoustic amplification to generate a benefit for everyday life [2]. In that case cochlear implants (CIs) increasingly become a treatment option. These implanted devices directly stimulate the auditory nerve fibers

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inside the cochlea and can provide hearing beyond the limitations of traditional amplification. Postoperative hearing results depend on several features like the length and the volume of the cochlea or the location and penetration depth of the CI [3].

In literature, there are some approaches to detect these features in computer tomography (CT) images especially with µCTs or ultra-high-resolution CTs [[4], [5]]. There are just a few investigations with conventional CTs which were mostly used in common medical examinations, such as Noble et al. [6]. Therefore, we aim to evaluate conventional CT scans to predict the hearing outcome after a CI implantation. Challenges with this kind of data are the very small structures of human cochleae and the worse resolution. This makes an extensive preprocessing essential which would not be necessary with a sufficiently high resolution.

The overall goal is the prediction of hearing outcome on basis of these features in preoperative CT scans before the CI is implanted. In a first step, the aim is to segment the human cochlea in existing clinical in vivo CT data where no influence can be exerted on the recording parameters such as orientation or field of view. As well as the appearance of the cochlea is described in the literature, the knowledge about what features lead to good or bad hearing after CI implantation, looks modest. Just a few of these features like the cochlear duct length [4] have been adequately investigated. Overall, mostly larger studies are missing for a sound statement. Especially, the correlation between cochlear volume and hearing outcome that we want to investigate, is not clear so far.

2. Methods

Usually conventional CT scans have a fairly low resolution, so that it is difficult to evaluate very small details in the human body such as a cochlea. The scans received are mostly recorded by scanners from Xoran Technologies and have a resolution of $0.3 \; x \; 0.3 \; x \; 0.3$ mm³. In relation, the cochlea has an approximate size of $7 \; x \; 7 \; x \; 4$ mm³ which corresponds to approximately $23 \; x \; 23 \; x \; 13$ pixels, but can vary widely. Since the cochlea is difficult to differentiate from the surrounding tissue, the data must be preprocessed. Therefore, the scans will be rotated in a way it is possible to see the typical snail shape in the coronal plane to simplify the segmentation such as Heutink et al. [4] did it. They reconstructed the scans of an ultra-high-resolution CT using filtered back projection, while we are using another method.

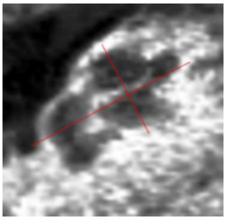


Figure 1. Axial slice of a conventional CT with the cochlear basal turn (CBT) of a right ear. The crosshair is aligned parallel and perpendicular to the long axis of the CBT and shows how the data has to be rotated.

In the axial plane, the cochlear basal turn can be detected. A straight line can be aligned parallel to the long axis of the cochlear basal turn represented by two manually set points. A second straight line can be aligned perpendicular to the first one as seen in

Figure 1. The resulting crosshair shows the orientation of the new coordinate system after rotation. The rotation angle can be determined with help of the Pythagorean theorem and the law of sines. The rotation itself takes place around the z-axis and the new pixel positions can be calculated by

$$\begin{pmatrix} x_{new} \\ y_{new} \\ z_{new} \end{pmatrix} = R \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}. \quad (1)$$

The rotation matrix R is determined by the rotation direction which depends on the side where the cochlea is located. The matrices for both, the left ear R_{LE} and the right ear R_{RE} are represented by

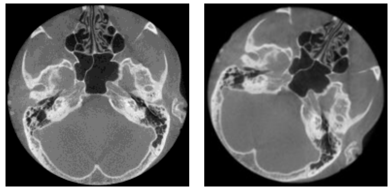
$$R_{LE} = \begin{pmatrix} -cos\delta & sin\delta & 0 \\ sin\delta & cos\delta & 0 \\ 0 & 0 & 1 \end{pmatrix}, R_{RE} = \begin{pmatrix} cos\delta & sin\delta & 0 \\ -sin\delta & cos\delta & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad (2)$$

with rotation angle δ. The z-coordinates stay unchanged. The new pixel data need to be converted in integers again, whereby the values are rounded up. It does happen that two or more colour information values are assigned to the same new pixel values. In that case, the mean value of all these colour information values is used. On the other hand, there will be some pixel positions which have not been filled. These empty positions will be filled by interpolated values with help of the 8-nearest neighbours which is fairly stable against outliers.

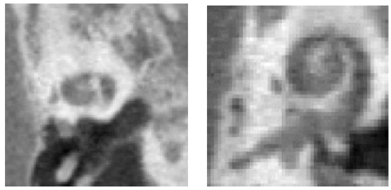
Now it is possible to see the complete snail shape of the cochlea in coronal view. This enables an easier segmentation of the cochlea which is initially performed manually. For a better contrast, some image processing techniques are applied. Because we are working with DICOM data, all colour information values are given in Hounsfield units (HU). Therefore, we first normalize the values for the further processing and select the region of interest. Afterwards, a contrast enhancement by histogram equalization follows and a better demarcation of the cochlea. As a preliminary stage of the segmentation, we used a thresholding technique. With the correctly chosen threshold the cochlea is separated from the surrounding tissue. All pixels not belonging to the cochlea will be deleted manually including the hearing nerve. We examine the cochlea up to the round window (Fenestra cochleae) which is typically done in the literature.

3. Results

After performing the described method, we compared our results with the literature especially Heutink et al. [4] and Pietsch et al. [5]. First step was the rotation by an angle $\delta = 35.78°$, which results in Figure 2b. In this example, the right ear cochlea should be considered, which is located left in the axial slice. The pixel size of the new data has increased in our example from $536 \, x \, 536 \, x \, 198$ pixels to $753 \, x \, 753 \, x \, 198$ pixels, while the number of axial slices remains.



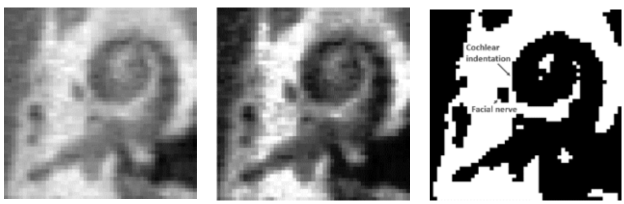
(a) Original axial slice (b) Rotated axial slice



(c) Original coronal slice with incomplete snail shape (d) Rotated coronal slice with complete snail shape

Figure 2. For a better view of the cochlea the conventional CT data has to be rotated. Afterwards, we can see the full snail shape which is typical for the cochlea in the coronal view.

The significant difference is that now the full snail shape of the cochlea can be seen in the coronal view (Figure 2d), which allows an easier segmentation.



(a) Original cochlear slice in coronal view (b) Cochlear slice after histogram equalization (c) Cochlear slice after additional thresholding

Figure 3. The conventional CT scan has an inferior quality compared to µCTs or ultra-high-resolution CT images. Left, near the cochlea, the facial nerve can be detected. Besides, there is a small cochlear indentation near the facial nerve. For the segmentation of the cochlea a previous image processing is essential.

Figure 3 shows the different stages of image processing, which is required to increase the contrast between the cochlea structure and the surrounding tissue. After the data was normalized, a region of interest with the full cochlea was manually selected. In Figure 3b the result after a histogram equalization for contrast enhancement is shown. With a suitable threshold (here $\theta = 0.43$), it is possible to separate the foreground (value 1) from the background (value 0). Left, near the cochlea, the facial nerve can be detected. Besides, there is a small cochlear indentation near the facial nerve. These features can also be seen in µCTs and ultra-high-resolution CT images [[4],[5]].

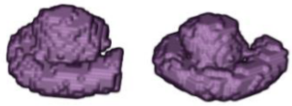


Figure 4. Rendered 3D representation of the segmented cochlea in two different views.

After thresholding the segmentation is almost complete and all that remains is deleting all pixels of the foreground, which not belong to the cochlea. We also cut off the hearing nerve and examine the cochlea up to the round window. Figure 4 shows a 3D rendered image of an example of a cochlea segment. This cochlea segment is formed by 3126 pixels with a single volume of 0.027 mm³. This results in a total volume of 84.4 mm³ or rather 0.0844 ml.

4. Discussion

Despite low resolution CTs the described method shows good results. In further research, more cochleae should be segmented for a correlation verification between volume or other features and hearing outcome after a cochlea implant surgery. The Hannover Medical School is the world's largest CI center with almost 10,000 patients being implanted in Hannover, so we have access to a very large amount of CT data. All patients who get a CI implantation hope for a significant better hearing afterwards and also an increase in quality of life again. The postoperative prediction of hearing outcome with the help of preoperative CT data would be a great innovation. Furthermore, it would be helpful for a more suitable surgical planning. For example, if we know, the patient has a fairly small cochlea the length of the CI could be adjusted and the risk for trauma could be decreased.

At the moment, we are still at the beginning to evaluate our data according to this scheme. After collecting a dataset with several manual cochlea segmentations, we want to train a neural network to perform this segmentation automatically. Because the data was collected with a variety of different CT scanners, it is very inhomogeneous in the case of field of views, resolutions or different number of serial recordings. Therefore, it is possible that we have to reject a certain part of the data we are not able to analyze. Besides it is possible that the cochlea segmentation with thresholding is too inhomogeneous that no volume comparison with hearing results is possible.

Acknowledgements

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