Alae Tracker: Tracking of the Nasal Walls in MR-Imaging

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Abstract. MR imaging opens the opportunity to image soft materials in the human body non-invasively and to observe the behavior of organs and muscles over a period of time. In this paper, a simple and easy-to-use method to track and measure the movement of the nasal walls during breathing is presented that uses a sum of three Gaussian functions as an estimator for the intensity distribution of the MR image. By post-processing MR-data it is possible to quantify internal nasal movement in a non-invasive manner. The approach shows very good results in comparison to manual segmentation and with respect to stability. Deviations of $\pm 10^\circ$ of the ROI still lead to sub-pixel accuracy. The software is available for download at http://www5.cs.fau.de/research/software/alae-tracker.

1 Introduction

For sufficient breathing human nostrils are kept stable by small cartilages in the nasal alae forming the outer nasal lateral walls. When instability of the cartilages occur, the nostrils can collapse during breathing leading to an obstruction of the upper airway. Until now there is no reliable diagnostic method to evaluate the stability of the outer nasal walls.

We propose to use MR Cine series [1] and a semi-automatic segmentation technique. In contrast to other methods no device needs to be inserted into the nose which has the risk of changing the nasal movement. It provides a non-invasive approach to track and measure the movement of the nasal septum and cartilages during breathing [2].

The method can be used to examine the movement of the inner nose in various applications including fundamental research, assessment of nasal function and monitoring of the rehabilitation process after nasal surgeries. The idea of this approach is to model the intensity distribution along a line through the human nose with a sum of three scaled Gaussian functions, such that the optima of the function coincide the intensity peaks of the nasal walls.

The approach as well as the mathematical background is more extensively described in Sec. 2. Here, the used data is described as well as the process to extract the necessary information from the MR image sequence and the tracking itself. In Sec. 3 the achieved tracking results are evaluated and the stability with respect to the position of the user-defined selection analyzed. Furthermore the results of the approach are compared with manual tracking of the nasal walls. Sec. 4 sums the results up.

2 Materials and Methods

We collected data with the following structure with the following properties: The image sequence shows the temporal progress during forced breathing in a cross section through the human head, such that the movement of the nasal walls can be observed. An example of one image is depicted in Fig. 1. In-vivo experiments were performed in one healthy volunteer on a 3T clinical MR scanner (MAGNETOM Verio, Siemens AG, Healthcare Sector, Erlangen, Germany), with software release syngo MR B17. Imaging was performed with the following parameters: TR/TE 2.45/155.31 ms, radio frequency excitation angle 10 °, FOV $192 \times 192\,\mathrm{mm}^2$, acquired matrix 96×93, reconstructed matrix 96×96, pixel-size $2\,\mathrm{mm}^2$, slice thickness 12 mm and a receiver bandwidth of 1021 Hz/Px.

The processing and evaluation of the image data consists of four steps: The line selection by the user, the reslicing of the image sequence, the estimation process and the extraction of the tracking result. For all steps the image processing framework ImageJ is used [3].

The first step of this semi-automatic segmentation process is user-driven: The user chooses a line in the above described image sequence centered through the nose. The line should be positioned in the center between the tip and the cheeks, approximately at right angle to the septum. Fig. 1 shows an example of the correct placement. The line selection denotes where the movement of the nasal alae will be observed.

The given image sequence is then resliced: For image $i, i = \{1, ..., n\}$ the intensities values along the line selections composed to the i-th image line of the resliced image [4]. The necessary information for the estimation is compressed into this one resliced image. The result can be seen in Fig. 3. This image is used for the estimation process and later to compactly display the tracked movement of the nasal alae, since each image line now depicts the position of the nasal walls at one point in time.

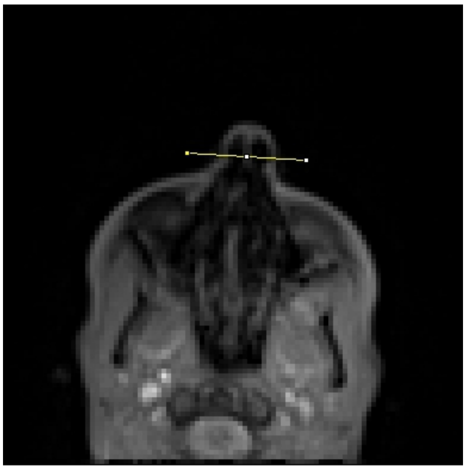
Based on the resliced image data, the estimation process is carried out for each image line i: The intensities are fitted to a sum of three scaled Gaussian functions. The idea is to model the intensity peaks that are the nasal walls each with a Gaussian bell function. The model function has the following form:

$$g_s(x) = \sum_{k=1}^{3} \alpha_k \mathcal{N}(x; \mu_k, \sigma_k), \tag{1}$$

where

$$\mathcal{N}(x; \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}. \tag{2}$$

Fig. 1. This figure shows the position of the cross section through the human head as well as an example for a line selection through the nose.



The measured intensities and the model function are then fitted using mean squared error. The function

$$\sum_{i=1}^{N}(f(x) - \sum_{k=1}^{3}\alpha_k \mathcal{N}(x;\mu_k,\sigma_k))^2 \rightarrow min \tag{3}$$

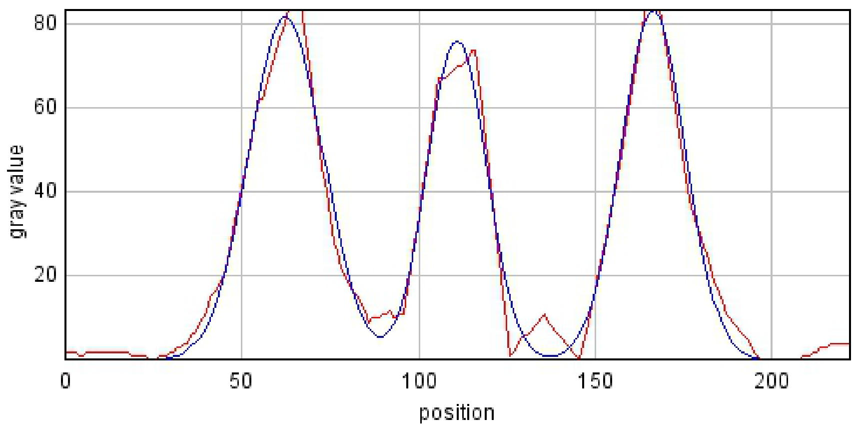
is minimized with respect to the free parameters mean μ_k, standard deviation σ_k and scaling factor α_k for $k = \{1, 2, 3\}$. In Eq. 3 the term $f(x), x \in 1, ..., N$ denotes the image intensity of the x-th pixel of the current image line, where N is the length of an image line.

For the optimization process, a gradient-decent method provided in the JPOP (Java Parallel Optimization Package) library is used[1]. As mentioned above the optimization and estimation process is performed for every point in time resp. for every image line in the resliced image, resulting in a temporal tracking of the motion.

Since the peaks of the Gaussian function are supposed to model the intensity peaks of the nasal walls, the mean values $\mu_k, k = \{1, 2, 3\}$ are the estimated positions of the nasal walls. The estimated mean values for each image line are drawn into the resliced image and the distances between the mean values are calculated (in mm) and put into a measurement table. This measurement table can be exported out of the ImageJ framework and used for further evaluation. Furthermore if the estimation process has failed, optionally interpolation can be used on the original image data set to artificially increase the resolution and/or a manual refinement of the tracking can be applied to improve the results.

[1] available at http://www5.cs.fau.de/research/software/java-parallel-optimization-package/

Fig. 2. Estimation of the intensity distribution (red) with three scaled Gaussian functions (blue) for one point in time.



To evaluate the method, a manual tracking of the motion of septum and cartilages has been performed on the available data set. Furthermore different initial manual selections for the tracking process were set to test the stability of the semi-automatic tracking and measurements.

3 Results

The achieved results reveal a very good agreement of the semi-automatic tracking with the intensity distribution of the MR-image. An example of the intensity distribution across the nasal septum and cartilages and the corresponding estimation with Gaussian functions is depicted in Fig. 2.

In Fig. 3 the complete estimate for points in time and the movement of the cartilages during breathing is shown. Again, we visually observe a good agreement between the automatic method and the image data. Note that the left nasal wall shows much more motion that the right nasal wall. The left wall has a maximum distance to the septum of 12.2 mm and a minimal distance of 5.4 mm. The maximal distance of the right wall to the septum is 11.4 mm while the minimal distance was 9.0 mm.

In addition, we investigated the stability of our method with respect to the manual ROI selection. We compared seven different configurations with the manual segmentation. The results are tabulated in Tab. 1. Using the same ROI as the manual segmentation, we get errors of about 0.5 mm which is below the pixel size of 2 mm. Also a slight change of orientation of $\pm 5°$ is still handled robustly by the method. In these cases the error is most at 1.21 mm. Even deviations of more than $\pm 10°$ still results in sub-pixel accuracy. With a shift of ± 4 mm the accuracy is reduced more. The highest error is 2.76 mm.

Fig. 3. The result of the reslicing (background) and the estimation process (yellow lines).

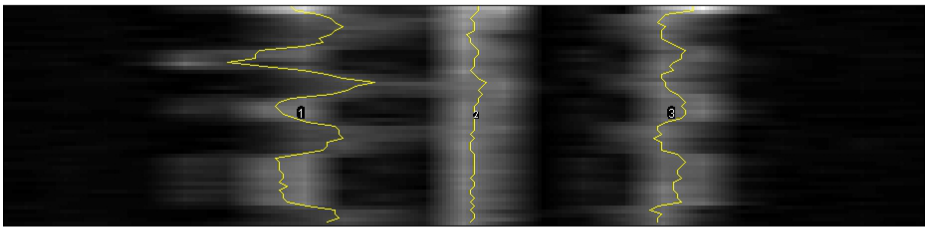


Table 1. RMSE with respect to manual segmentation. Using the same ROI as for the manual segmentation, we observe sub-pixel accuracy. Also small deviations still preserve the sub-pixel accuracy. Larger deviations lead to an accuracy of about one pixel.

ROI	same	$-5°$	$+5°$	$-12°$	$+11°$	$+4$ mm	-4 mm
pos. left	0.54	0.68	0.85	0.89	1.10	1.48	1.41
pos. septum	0.42	0.33	0.51	0.38	0.90	1.07	1.10
pos. right	0.23	0.33	0.24	0.50	0.60	0.47	1.67
dist. left	0.85	0.81	1.21	0.95	1.46	2.26	1.48
dist. right	0.46	0.34	0.50	0.45	1.60	0.94	2.76

4 Conclusion

We presented a method for semi-automatic tracking of the nasal wall in MR Cine sequences. This is the first approach to objectively detect a collapse of the nasal alae and measure the stability of the nose during breathing. The method was based on modeling the intensity profiles as Gaussian bell curves. We could show that the fitting procedure worked well compared to a manual segmentation. The error was below one pixel. Also slight modifications as they occur in the manual ROI selection process were handled by the method robustly. Small deviations resulted in only a small increase of the error. Deviations of up to 10° yielded sub-pixel accuracy. However, shifts perpendicular to the orientation of the ROI line have to be handled with care. Deviations of two pixels already result in errors of about one pixel. We regard this problem as rather minor as the position in this direction can be selected robustly from the anatomical information in the image. To further improve the results we suggest Kalman Filtering to reduce the influence of noise in the MR data.

References

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