Enhanced airway-tissue boundary segmentation for real-time magnetic resonance imaging data

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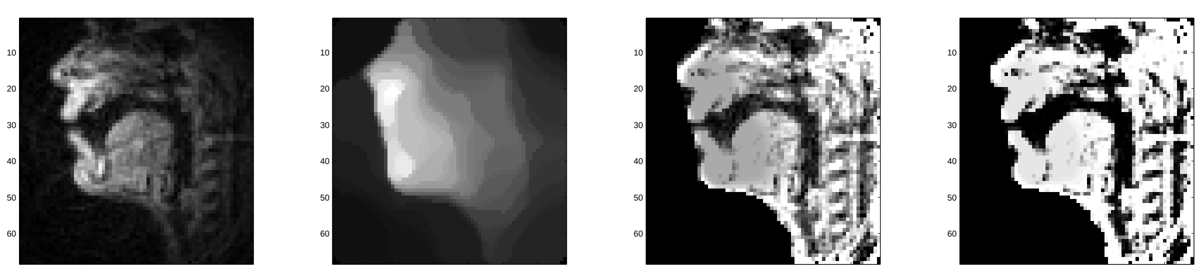
Real-time Magnetic Resonance Imaging (rtMRI) [1] is an important tool for studying human speech production, providing video data of speech articulations in the entire mid-sagittal plane. The airway-tissue boundary segmentation in the MR images is often required as a pre-processing for the analysis of the vocal tract movements. Performing this segmentation automatically is essential for analyzing rtMRI data comprising hundreds or thousands of video frames, the complex structure of the vocal tract, non-uniform sensitivity of the tissues in head and neck, noise, and the rapidly varying irregular vocal tract shape make this problem challenging. This paper presents an algorithm for analyzing the MR images, which includes (1) retrospective intensity correction of the MR images, (2) detection of the front-most edge of the lips and the top of the larynx, (3) segmentation of airway-tissue boundary in the vocal tract, and (4) measurement of the distance between the upper and lower tissue boundaries. The current method improves the robustness of tissue boundary estimation by using a data-driven way of pre-processing of the MR images, airway path estimation in a constrained region, and optimal tissue boundary estimation, over the previous method [2].

The present algorithm uses a multi-resolution approach to minimizing the effects due to the noise, artifacts, and non-uniform field sensitivity of the tissues. First, a smoothed image S of an original MR image O is created by a morphological closing operation. The intensity corrected image C is created by multiplying the pixel intensity of O and the inverse of the pixel intensity of S, while setting the non-tissue pixel intensity to be zero. The final image F is created by sigmoid-kernel-based intensity warping on C. Fig 1 (a), (b), (c) and (d) illustrates the original MR images, the smoothed images, the intensity maps, and the final images, respectively.



(a) Original image (b) Intensity map (c) Intensity correction (d) Intensity warping

Figure 1: The MR image after each pre-processing.

After a grid construction adopted from the previous method [2], the present algorithm finds the optimal grid lines for the top of larynx (the initial grid line) and the front-most edge of the lips (the final grid line) by using the Viterbi algorithm. Each state corresponds to each of the grid lines near the lips or larynx; The state transition matrix is the inverse of Euclidean distance among the grid

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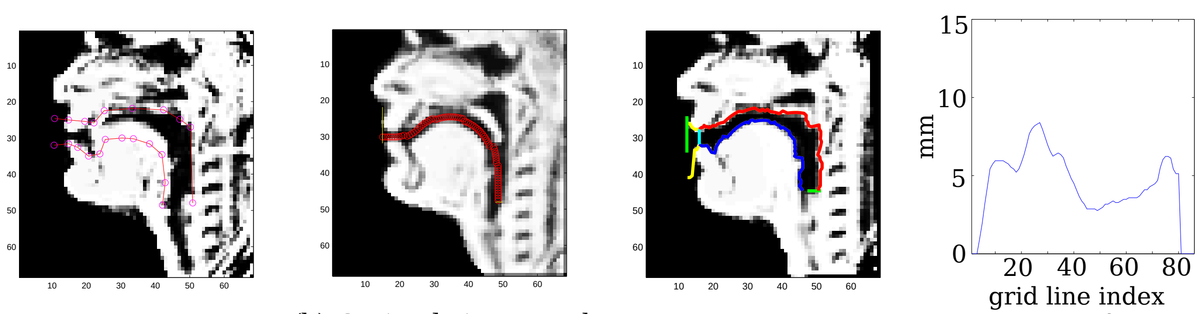
lines; The likelihood score is the maximum pixel intensity of a grid line at image frame for the lips detection, while it is the mean of the first-order derivatives of pixel intensities for the larynx detection. The length and the size of grid lines are determined by users.

The key idea behind improving airway-tissue boundary segmentation is to find an accurate and possibly approximate airway path in the upper airway first, from which the optimal airway-tissue boundaries can be determined easily and more robustly. The optimal airway paths passing through all grid lines in an MR image is determined by using the Viterbi algorithm, where the optimal airway path is found to by maximizing the score of possible paths. For this problem, each possible path in a grid line corresponds to each state. The algorithm prompts the user for a few points, based on which constraint lines are created by interpolation of the points. The regions outside of the constraint lines are not used for estimating the airway path line by setting the likelihood scores of corresponding bins to be zero. The state transition matrix is similar to the ones defined for lips detection. The estimated airway path in our method can still stay within the region of interest during full contact of articulators, restricted by the transition costs between states and the constraints.

Two airway-tissue boundaries, one for the outer boundary and the other for the inner boundary, for each grid line are determined at the first bins whose pixel intensity is over a certain threshold in the outer direction and the inner direction, respectively. Finally, a distance function for the airway-tissue boundaries is obtained by computing Euclidean distance between the outer and inner boundaries for each grid.

Fig. 2 illustrates the results of each procedures: interpolated constraint lines in (a), an optimal airway path (red color) and estimated lips and larynx positions (yellow color) in (b), estimated airway-tissue boundaries (red color for top-right boundary and blue color for inner boundary), the initial and final grid lines (green color), and the minimum distance grid line in lips region (cyan color) in (c), and an estimated distance function of the upper airway in (d).



(a) Constraint lines (b) Optimal airway path (c) Tissue boundaries (d) Distance function

Figure 2: Interpolated constraint lines, results of airway-path estimation and of airway-tissue boundary estimation, and estimated distance function.

References

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[2] Michael Proctor, Danny Bone, Nassos Katsamanis, and Shrikanth S Narayanan, "Rapid semi-automatic segmentation of real-time magnetic resonance images for parametric vocal tract analysis," in *Proceedings in Interspeech*. 2010, pp. 1576–1579, ISCA.