Robust Rib Cage Segmentation in CT Image Series Using Active Contour Models

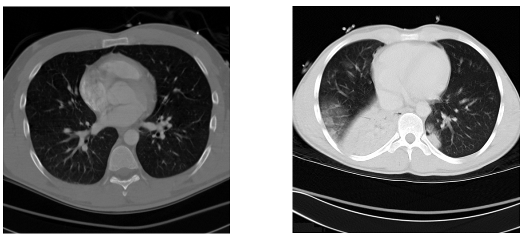
Alexandru P. Condurache, University of Lübeck, Germany, Edward A. Essah, University of Lübeck, Germany, Andreas Reske, University Hospital Leipzig, Germany, Matthias Seiwerts, University Hospital Leipzig, Germany, Harald Busse, University Hospital Leipzig, Germany, Til Aach, RWTH Aachen University, Germany, Ulrich G. Hofmann, University of Lübeck, Germany

Abstract

We report on initial approaches to automatically segment healthy and atelectatic lung areas in CT images for diagnostic purposes such as quantification of aerated and atelectatic pulmonary subvolumes. We address mainly the problem of automatic segmentation of the chest wall, including the lung parenchyma in the presence of atelectasis as in this case the differentiation between atelectatic lung parenchyma and surrounding thoracic soft tissue is often complicated. We propose an adequately parameterized active contour model (snake) for the segmentation. The snake evolves under the influence of the image based external forces to the border between the normal lung and the chest wall tissue and rests there. At the same time the internal forces will halt the snake on the approximate border between the chest wall and the atelectatic lung thus segmenting the lung compartment including the atelectatic area.

1 Introduction

Thoracic CT-scanning can be used to support enhanced investigation of the lungs' functioning parameters both for healthy and Acute Respiratory Distress Syndrome (ARDS) lungs [1,2]. For this purpose we need to segment the lung tissue area in each CT-slice [3]. An image gray-level based or an edge segmentation of the lung parenchyma is particularly difficult when atelectatic lung regions are neighboring to thoracic soft tissue structures, as in such a case, the atelectatic lung and the soft tissue may be characterized by similar gray levels. An example is shown in **Fig. 1**.



(a) (b)

Fig. 1 Healthy (a) and atelectatic (b) lungs

Previous approaches to this segmentation problem used Bezier curves to find the lung boundaries. The control points were determined using the ribs, sternum and vertebrae. In critical areas, the control points were placed using the relative position of the detected bones to one another [3].
In this contribution we propose to find the correct lung boundaries by active contours. Active contour models or snakes [4] are energy minimizing curves attracted by image (external) forces to nearby features such as edges. Their behavior is regularized by internal forces which are opposed to stretching and bending.
Such internal forces ensure that the solution found in critical image areas is a smooth interpolation between properly constrained points of the active contour.
For lung segmentation we propose to use a closed snake which is automatically initialized using the bones observable in the analyzed images.
For a robust automatic segmentation, the snake evolves in two stages, each time using different external forces. For the first stage, the external force is computed after the image was morphologically processed so that only bony structures remain. Thus we avoid that the snake hangs on the borders of the atelectatic lung instead of the true lung boundaries. Then, for a precise segmentation, during the second stage the external force is computed using the original image.

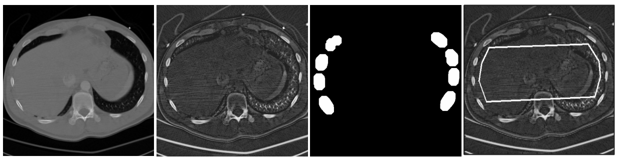
2 Methods

2.1 Rib segmentation and snake initialization

To robustly and automatically initialize the active contour model we use the ribs which are visible in all interesting images. Thus we first segment them, and then find their extended convex hulls. The points on the convex hull border closest to the image centre are used to define the initialization curve.

Bones appear in the analyzed images as small structures brighter than their surroundings. For a successful segmentation we first select such image structures by a morphological Tophat-like transform [5].

We then threshold (e.g. percentile threshold or histogram based threshold [6]) the Tophat result to find bone pixels. This segmentation result is typically fragmented and in some cases some bones are not detected or contrast medium containing noise structures such as the aorta and portions of the heart are also segmented. To ensure a proper initialization of the snake, the segmentation result is processed to obtain the extended convex hull of each detected rib. For this purpose, first the distances between each segmented pixel and the image centre are computed. Segmented pixels with distance below a certain threshold [6] are eliminated from the segmentation as the ribs are characterized by larger distances to the image centre. Then the image is dilated, so that the objects present are connected, obtaining thus the extended rib convex hull. The points on the convex hull closest to the image centre are used to initialize the active contour. An example is shown in **Fig. 2**. Here we have processed an image showing part of the diaphragm which is more challenging as the grey levels characterizing the chest wall tissue and the diaphragm are nearly the same.



(a) (b) (c) (d)

Fig. 2 Original image (a), Tophat result (b), extended convex hull (c) and initialization (d)

2.2 Snake for lung segmentation

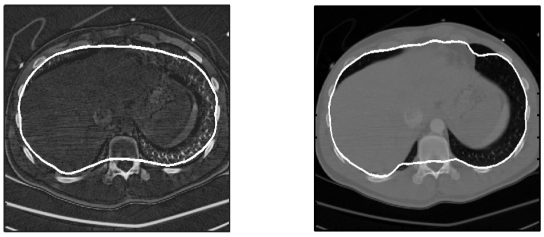
Starting from the initial contour, the snake evolves on the Tophat result, to avoid stopping on the edges of the atelectatic lung tissue. To compute the external forces in this case the terminal functional is used [4]. Also to ensure that the snake reaches the desired contour, a balloon force is added [7].

For a precise segmentation the solution obtained after the snake stops evolving (once a certain percentage of the snake points no longer move) is used as initialization for a second stage where the snake's external energy is computed using the original image. An example is shown in **Fig. 3**.

3 Commented experiments

We have tested the proposed method on several CT images showing atelectatic tissue or the diaphragm with good results. The active contour is able to find an optimal (i.e. smooth) chest wall border in the image regions where this is hardly or not at all detectable. This is shown in **Fig. 3**.

Problems still appear where the atelectatic lung or the diaphragm is separated from the chest wall only by a thin portion of normal lung. In such cases the snake may hold on to the border of the atelectasis instead of the chest wall border.



(a) (b)

Fig. 3 Lung boundary segmentation at the end of stage one (a) and final result after stage two (b)

4 Conclusions

The active contour is able to use available lung border image information to approximate it in pathological cases. The way this approximation is computed can be controlled by weighting the internal forces. We report on initial approaches to a robust automatic method for segmentation of the rib cage in the presence of atelectatic lung. We use snakes to achieve a border based segmentation as by their force formulation they are able to find also apparent contours.

5 Literature

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