DETECTION AND VALIDATION OF LUNG FIELD CONTOURS ON CHEST RADIOGRAPHS

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ABSTRACT

The purpose of the research herein presented is the automatic detection of lung boundaries in posterior-anterior digital chest radiographs. The precise location of the two lungs is important in a computer-aided diagnosis system as it allows the reduction of the region under analysis, decreasing the computation time and facilitating data compression. Furthermore, it allows the delimitation of the search area, easing the selective tuning of the abnormalities detection algorithms. The results produced by the automatic method were validated by comparison with manual contours traced by an experienced radiologist. For this particular purpose, two programs with friendly interfaces were developed. The achieved comparison results demonstrate the good performance of the automatic method.

KEY WORDS

Medical image processing, image analysis, computer-aided diagnosis, chest radiographs.

1. Introduction

During the last decade several efforts have been made in order to automate the quantitative analysis of chest radiographs, having in mind the development of computer based systems that can act as complementary tools for supporting medical decisions. Several authors considered the detection of the lung fields as an important preliminary step for such automatic procedures.

The lung field detection problem has been addressed using distinctive approaches. Tsujii \textit{et al} [1] used an adaptive-sized neural network for image segmentation using pixel-based features. A very long time consuming algorithm (about thirty minutes) is the main drawback of the method mentioned by the authors. Armato \textit{III et al}. expanded previous work for automated posterior-anterior (PA) lung image segmentation [2] to lateral chest radiographs [3]. They adopted an iterative global gray level thresholding to obtain an initial contour, followed by local thresholding, contour smoothing and curve fitting to obtain the final lung delineation. In [4], Carrascal \textit{et al.} estimate the total lung capacity based on the delineation of posterior-anterior and lateral chest radiographs. In [5], Ginneken \textit{et al.} compare several approaches for the automatic segmentation of lung fields, obtaining the best performance with a hybrid scheme that uses a combination of a rule-based segmentation algorithm with a pixel-based scheme. The obtained accuracy approaches the theoretical limit of inter-observer variability, outperforming other algorithms. As the authors point out, an extensive evaluation of several algorithms needs to be tested in a common database. Li \textit{et al.} [6] use the first derivative of horizontal/vertical image profiles together with image feature analysis to determine lung boundaries. The authors refer that some difficulties still remain in the detection of the medial and hemi-diaphragm edges.

In this paper, an automatic procedure for the detection of the lung fields in PA chest radiographs is presented. An edge-based approach was chosen, where the individual edge points detected on the lung border are combined to produce a final closed contour using a spline approximation method. In Section 2 we briefly report the methodology that is used for this purpose. The lung field contours generated by this algorithm were validated by comparison with those traced by an experienced radiologist. The programs specially implemented for this validation task are described in section 3. The comparison results and some conclusions are presented in sections 4 and 5, respectively.

2. Lung field detection

The lung field detection task is accomplished in two phases: in the first one, two rectangular regions of interest (ROIs) are determined, each one containing one lung field; in the second phase, ROIs are analyzed in order to obtain an accurate location of lung boundaries. Both phases are fully automatic, without requiring any kind of user intervention.

Lung field ROI delimitation aims at defining restricted rectangular areas that surround, as close as possible, each
lung field. The proposed methodology is based on the projection of rectangular image regions onto horizontal and vertical directions; as extreme values of these projections are usually associated with the limits of lung field regions, an iterative procedure was defined where the currently calculated region limits were used to reduce the image area to analyze, until a final result is achieved. Figure 1 illustrates the result of ROI delimitation. The preliminary detection of the right and left ROIs allows an initial coarse localization of the lung fields, decreasing the complexity of the algorithms used in the second phase to achieve accurate lung contours. All subsequent processing steps are strictly applied to these two ROIs.

![Figure 1 - Original image with ROI limits overlapped.](image)

After ROI delimitation, the process for the detection of precise lung field contours starts with image smoothing by an 9×9 average filter. The dimension of the filter was selected to balance contour smoothness and accurate localization of boundary pixels. The sequence of operations used to extract lung borders can be summarized in the following steps:
- detection of mediastinal and costal edge pixels;
- detection of top and bottom edge pixels;
- elimination of outside edge pixels;
- combination of remaining edge pixels to achieve a closed contour.

![Figure 2 - Detection of mediastinal and costal boundaries: a) edges in first stage; b) spline fitting; c) edges detected in second stage.](image)

Mediastinal and costal edge points are detected on the image that results from the application of a 1-D first derivative Gaussian filter to image rows. In this filtered image, positive values are associated with increasing intensity transitions, while negative values correspond to decreasing variations. Therefore, mediastinal and costal edge points are represented by derivative maxima and minima, respectively. These points are searched for on opposite sides of the central curve. However, in some regions several significant values for maxima and minima can be found in the same row; when this situation occurs the selection of the correct extreme is difficult.

To overcome this problem, detection is performed in two stages. In the first stage, only those edge points that correspond to a single maximum on a row are kept as mediastinal edge pixels; the same procedure is applied to single minima, in what concerns costal edges. Initial approaches to mediastinal and costal lung borders are obtained by fitting splines to these two groups of detected pixels. In the second stage, the image that resulted from the 1-D first derivative Gaussian filter is once again analyzed, and when several maxima occur in the same row, only the one that is closer to the mediastinal spline is chosen. The same procedure is repeated for costal edges. Because mediastinal edge segments are usually irregular and have different lengths, further smoothing is achieved by eliminating short segments far from the local dominant direction. Figure 2 shows the results of mediastinal and costal boundaries detection on the right ROI of figure 1.

![Figure 3 - a) Bottom edge pixels; b) and c) detection of lung field top boundary.](image)

In the upper region of the lung the presence of the clavicle is very disturbing because derivative values are usually strong. So, when the search for maxima in the columns is performed, points can be detected both in lung and
clavicle borders. Another intrinsic feature of this region is the occurrence of pairs of extreme points. Figure 3b illustrates these two kinds of effects. From the two points of each pair, only the one corresponding to bright-to-dark transition is kept. To discriminate between lung and clavicle edges, all points occurring beyond the exterior part of the costal boundary are eliminated. A final segment is obtained through a search procedure that uses as starting point the edge point closer both to ROI top limit and to lung field central line. In this search process, extreme points in image columns are aggregated if their vertical distance from those already selected is within a predefined limit. The final result of top border detection can be observed in figure 3c.

At this point, it is possible to eliminate some edge points that were erroneously detected. For instance, all bottom edge points beyond costal border and between lung field central line and mediastinal border can be discarded. Figure 4a presents the set of edge pixels detected along the four lung borders that were kept after the elimination procedure. The four splines fitted to each one of these pixel sets are shown in figure 4b. The final closed contour, obtained after calculating the intersection points of these curves are presented in figure 5.

The methods described in this section were tested in a set of forty-seven chest radiographs. The algorithm only failed to determine useful lung field contours in three images (one wrong lung field contour in each image). The causes were an incorrect detection of the ROI for one lung field, the presence of an image artifact (patient necklace) and a low image contrast in one top mediastinal area. Some additional detection examples were presented in a previous paper [7].

### 3. Validation of lung field contours

In order to validate the contours obtained using the automatic method, we asked an experienced radiologist to manually delineate the lung contours for the images that were used to test the algorithm. For that purpose a Lung Contour Editor was developed. The results of the automatic and manual traced contours were compared with a Lung Contour Comparator.

The Lung Contour Editor allows experienced users, particularly physicians, to trace and edit the lung contours by hand. To facilitate this task, the friendly interface shown in figure 6 was conceived. The editor allows the tracing of new contours, by insertion of a number of landmarks, the modification (deletion and moving) of landmarks and the replacement of contour segments. Several visualization options are available, including the zooming of the image, in order to allow a more accurate tracing of the lung contour. A traced contour is saved in a database and is automatically shown to the user when the corresponding X-ray image is selected.

The main purpose of the Lung Contour Comparator is to allow the comparison of the contours manually traced by physicians, used as ground truth, with those obtained by the automatic method. The quantitative results of the program are several areas of regions resulting from the superposition of the two compared contours, as illustrated in figure 7. In this figure, the comparison values shown represent: the area enclosed by the manual contour (Area 1), used as ground truth; the area inside the automatic contour (Area 2); the correctly segmented area (Area 1 & 2); the area of false negatives, defined as the area that is inside the manual contour but outside the automatic one (Area 1 & ~2); the area of false positives, representing the area that is interior to the automatic contour but exterior to the manual one (Area ~1 & 2). All these results are saved in a text format that can be imported by a worksheet tool, for posterior processing.
Figure 6 - Lung Contour Editor interface.

Figure 7 - Lung Contour Comparator interface.
4. Results

Table 1 summarizes the results obtained after comparing the lung borders delineated by the manual and the automatic procedures for the test set of forty-seven images. The automatic contours were achieved using the algorithm described in section 2. For the manual borders, an experienced radiologist was asked to define the lung fields.

The values included in this table are the averages of the forty-seven individual values obtained in the test. As said before, for each image the manual delineated area was used as ground truth for calculating the percentages shown in this table.

Figure 8 illustrates some results of this validation process. From these four examples, it can be observed that in the first three images the automatic contour is very similar to...
the manual one. In the last image, the automatic contour for the right lung was not detected correctly, because the algorithm failed to locate the top limit of the ROI; this is one of the rare cases where the detection algorithm failed to produce a useful result [7].

Table 1 - Comparison results for the images in figure 8 (percentage values)

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Right lung</th>
<th>Left lung</th>
</tr>
</thead>
<tbody>
<tr>
<td>8a</td>
<td>98</td>
<td>96</td>
</tr>
<tr>
<td>8b</td>
<td>97</td>
<td>95</td>
</tr>
<tr>
<td>8c</td>
<td>97</td>
<td>94</td>
</tr>
<tr>
<td>8d</td>
<td>86</td>
<td>84</td>
</tr>
</tbody>
</table>

Table 2 summarizes the results obtained after comparing the lung borders delineated by the manual and the automatic procedures for the test set of forty-seven images. The automatic contours were achieved using the algorithm described briefly in section 2. For the manual borders, an experienced radiologist was asked to define the lung fields.

The values included in this table are the averages of the forty-seven individual values obtained in the test. As said before, for each image the manual delineated area was used as ground truth for calculating the percentages used to calculate the values shown in table 2.

Table 2 - Average comparison results of the manual and automatic contours in 47 images (percentage values)

<table>
<thead>
<tr>
<th></th>
<th>Right lung</th>
<th>Left lung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 2</td>
<td>94.0</td>
<td>96.6</td>
</tr>
<tr>
<td>Area 1 &amp; 2</td>
<td>91.5</td>
<td>93.0</td>
</tr>
<tr>
<td>Area 1 &amp; ~2</td>
<td>8.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Area ~1 &amp; 2</td>
<td>2.5</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The values in tables 1 and 2 reflect the success of the contour detection algorithm. The analysis of the individual results has demonstrated that, in general, the contours are close, but interior, to the manual one. These facts show up in the values presented in table 1, as the superposition area (Area 1 & 2) is greater than 90% and the area of false negatives is greater than the area of false positives.

5. Conclusion

This paper presents an automatic procedure for the detection of the lung fields in posterior-anterior chest radiographs. The contours determined by the method were validated by comparison with lung borders delineated by an experienced radiologist. The results confirmed the good performance of the automatic method. However, the fact that the automatic contour is usually interior to the manual one excludes some points that would otherwise belong to the lung. This is an undesirable consequence of the smoothing steps associated with the contour delineation procedure, but it can be easily compensated.

The lung field contours that result from the automatic procedure described in this paper are currently being used to delimit the area of the images that will be further analyzed in order to automate the detection of lung nodules.

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