Impact of segmentation techniques on the performance of a CT texture-based lung nodule classification system

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Purpose

Lung cancer is one of the four most common cancers worldwide [1]. It is associated with a high mortality rate and is often at an advanced stage at the time of diagnosis. A number of cancer institutions have implemented CT based lung screening programs to increase early detection for individuals at risk between the ages of 55-74 years with an extensive cigarette smoking history [2]. Nodules are quite common in screening and as incidental findings on CT scans. Therefore one of the important steps for clinical management is the stratification of pulmonary nodules (PNs) on Chest CT.

We have previously proposed a Computer Aided Diagnosis (CADx) pipeline based on Quantitative Texture Analysis to support the reading radiologist in correctly stratifying nodules [3-5]. This clinical decision support system consists of a number of automatic and user-dependent steps. Lesion segmentation is one such main pre-processing task which produces technique- and user-dependent outputs. In this work, we studied the impact of using a semi-automatic segmentation technique versus manual contouring on the classification performance of our system.
Methods and materials

Patient Database

- A retrospective dataset comprising 322 pulmonary nodules (PNs) from 186 patients.
- Inclusion criteria:
  - Patient with PNs reported, from January-April 2013.
  - CT scan available for analysis in thin-slice sections.
  - Ground Truth diagnosis established by histology for malignant nodules and histology or 2 year follow-up with no nodule growth for benign nodules.
- Collection was made across a single geographic population covered by the Oxford University Hospitals Trust NHS region.

Nodule contouring

Each PN was manually contoured using commercially available software (XD3, Mirada Medical Ltd., UK). A second contour was obtained for each PN using a proprietary semi-automatic Otsu based thresholding method. This algorithm was developed and validated on an independent dataset prior to this study and requires two user click-points (a centroid and a radius) to initialise the segmentation.

Texture Analysis

A total of 792 texture features were extracted from each contour in 2D and 3D. This included filter-based features (Laws, Gabor, Laplacian of Gaussian), features derived from the GLCM (Grey-Level Co-occurrence Matrix), Fractal Dimension, First Order Statistics, and combined features [6].

Feature selection

A greedy-algorithm was used to select the most discriminative 20 features for each nodule contouring technique.

Learning and statistical evaluation
• Overlap between Manual and Otsu masks was compared using the DICE score.
• A Support Vector Regressor (SVR) and leave-one-out training and validation strategy were used to map selected features onto malignancy probabilities (from 0 to 100%).
• Overall model performance were compared using the area Under the Receiver Operating Characteristic curve (ROC).

**Computation and statistical analysis**

Image analysis tasks were performed using MATLAB 2015a (The Mathworks, Natick, MA, USA). Statistical analyses and data visualization were generated using R (version 3.2.1) [7] in RStudio (version 0.99.467) with the gglot2 library [8].
Results

*Nodule contouring*

The Otsu segmentation method returned a contour for 315 nodules in 184 patients. The method failed in 7 (2.2%) cases (4 GGOs, 2 cavitating nodules and 1 small nodule) which were excluded from subsequent analysis. The remaining cases included 158 benign and 157 malignant nodules (84 primary, 72 pulmonary metastases, and 1 unidentified).

Volumes ranged from 7.01 mm$^3$ to 11,961.05 mm$^3$ for Manual and from 1.05 mm$^3$ to 12,450.06 mm$^3$ for Otsu segmentation (Table 1, Figure 1.A). Overall, volumes derived from Manual segmentation (mean: 945.50 mm$^3$; median: 265.60 mm$^3$; SD: 1676.26 mm$^3$) were bigger and more spread in size than volumes derived from Otsu segmentation (mean: 632.66 mm$^3$; median: 193.42 mm$^3$; SD: 1231.82 mm$^3$).

Agreement between contours, as measured using the DICE score, was moderate (0.76 ± 0.21; mean ± SD) (Table 1, Figure 1.B).

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
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<tbody>
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<td>Manual volume (mm$^3$)</td>
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<td>265.60</td>
<td>1676.26</td>
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<td>11961.05</td>
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<tr>
<td>Otsu volume (mm$^3$)</td>
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<td>193.42</td>
<td>1231.82</td>
<td>1.05</td>
<td>12450.06</td>
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<td>DICE score</td>
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<td>0.82</td>
<td>0.21</td>
<td>0</td>
<td>0.99</td>
</tr>
</tbody>
</table>

*Impact of segmentation technique on classification performance*

Strong visual agreement was observed between feature values derived from Manual versus Otsu in most cases (Figure 2).

We found no difference in classification performance for Manual and Otsu segmentation (AUC=0.85±0.02 and 0.85±0.02, respectively). Similarly, we found no difference when training on Manual and testing on Otsu, or training on Otsu and testing on Manual (AUC=0.82 and AUC=0.83 respectively). ROC curves are shown in Figure 3.
Fig. 1: Distribution of volumes and DICE scores (A) Lesion volumes estimated using Manual (red) and Otsu (green) segmentation. (B) DICE scores.

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Fig. 2: Visual agreement between feature values for the two segmentation techniques. Results for the 20 features selected on the Manual segmentation set.

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Fig. 3: Impact of segmentation technique on CADx classification performance. ROC curves for different segmentations and training/testing sets.

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Conclusion

Overall classification performance, as measured using ROCs, were not affected by the segmentation technique.
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