Computer-Aided Detection of Solid and Ground Glass Nodules in Thoracic CT images using two independent CAD systems

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Abstract. In computed tomographic lung cancer screening, both solid and ground glass nodules are regularly encountered. Ground glass nodules may or may not have a solid component and it has been shown that they have a much higher chance of being malignant in comparison to solid nodules. Computer-aided detection (CAD) systems designed for solid nodules perform poorly on detection of ground glass nodules, and vice versa. Therefore, a CAD system that combines the output of two prototype CAD systems aimed at detection of ground glass nodules and solid nodules, respectively, could lead to efficient detection of the entire spectrum of lung nodules in chest CT scans. In this study, we combine the output of two prototype CAD systems and show results on a data set of 73 CT examinations containing both solid and ground glass nodules. The main category of nodules which are found by both CAD systems are ground glass nodules with a solid component.

1 Introduction

In computed tomographic (CT) lung cancer screening, both solid and ground glass nodules are regularly encountered. Ground glass nodules (GGNs) have an increased attenuation but do not, like solid nodules, completely obscure the lung parenchyma [1], although they may have a solid component. These nodules are relatively rare, but it has been shown that they have a much higher chance of being malignant, in particular the ground glass nodules with a solid component, also referred to as part-solid or mixed nodules [1]. Therefore, early detection of these nodules is of major importance.

Many computer-aided detection (CAD) systems have been designed for detection of solid nodules, but only few studies regarding ground glass nodule detection have been published [2,3,4,5,6]. Solid nodule CAD systems perform poorly on detection of GGNs [7] and therefore, combination of a prototype CAD system for detection of solid nodules and a prototype CAD system for GGNs could lead to efficient detection of the entire spectrum of lung nodules in chest CT scans.

In this work, we focus on the combination of two prototype CAD systems for detection of solid and ground glass nodules, respectively. Both prototype CAD systems will be explained briefly and the combination of these CAD systems is explained. Finally, we will evaluate which lung nodules are detected by both systems. Since we expect that a solid nodule CAD system is sensitive to the solid component of a GGN, we hypothesize that especially part-solid nodules will be detected by both systems.

2 Data

A total of 73 thin-slice, low-dose CT examinations from 31 patients from the Dutch Belgian randomised lung cancer screening trial (NELSON) were provided for this study [8]. This data has not been used for training of either of the prototype CAD systems. The data set is a subset of a larger collection of all CT scans from one of the sites of the NELSON screening trial in which at least one GGN was annotated. Since GGNs are relatively rare, a random set from all NELSON data would likely not contain many GGNs and therefore, we choose to select a set of CT scans that contain both GGNs and solid nodules. All CT examinations were performed with a slice thickness of 0.7 mm and the in-plane voxel size varied between 0.52 and 0.84 mm.

3 Methods

3.1 Solid nodule CAD

The prototype CAD system for automatic detection of solid lung nodules has been published by Murphy et al. in 2007 and 2009 [9,10]. This system is in its essence designed for all lung nodules, but it performed poorly on detection of ground glass nodules [10] and therefore we refer to it in this paper as the solid nodule CAD system. It has been extensively tested on data from the NELSON screening database. In addition, this CAD system was also evaluated in the ANODE09 study and it showed best performance compared to five other algorithms on a data set of 50 low-dose CT scans [11].

The system starts by subsampling to isotropic voxel data in which the in-plane resolution is changed to 256×256. Prior to nodule candidate detection, a lung segmentation algorithm based on region growing is used to segment the lungs [12]. Nodule candidates are extracted using shape index and curvedness at a fixed scale of 1 voxel. If the shape index and curvedness values of a voxel are within certain predefined thresholds, the voxel is selected as a candidate. Subsequently, neighboring candidate voxels are clustered into candidate regions. This procedure typically produces about 700 candidate clusters per scan.

A two-step classification approach using k-nearest neighbor (kNN) classification is used to remove false-positive candidates. The feature set is calculated from gray values, image intensity gradients, shape index values and curvedness values. Values within the candidate cluster and in areas around the cluster are inspected to extract features. Then, in the first classification step, many obvious false positive clusters are removed using a small number of relatively simple features. Using sequential forward floating selection (SFFS), eight features were selected for this first step. In the second classification step, more complex features are calculated in order to remove the more difficult false positive clusters. Note that these more complex features are not computed for the candidate clusters which are removed in the first step. Again, SFFS was used and the best 19 features were chosen for the second classification step.

Training of the system is performed using a data set of 580 CT scans from the NELSON screening trial in which all NELSON annotations were used as reference. Previously, the system was validated on 813 scans from the NELSON screening trial and reached a sensitivity of 80.0% at an average of 4.2 false positives per scan (FP/scan) [10].

3.2 GGN CAD

Automatic detection of ground glass nodules is accomplished using a recently published GGN CAD system [6]. The system is aimed at detection of GGNs and therefore, no evaluation regarding performance on detection of solid nodules is presented in [6].

The complete pipeline of the GGN CAD system consists of initial segmentation steps, candidate detection, feature extraction and classification. The initial segmentation steps consist of a lung and airway segmentation [12,13]. Candidate detection is based on a double global threshold on Hounsfield Units (HU), followed by a morphological opening and finally, connected component analysis is used to extract candidate clusters. Small candidate clusters which would not require follow-up CT according to current clinical guidelines are removed. On average, the candidate detection step resulted in 524 candidate regions per scan.

A rich set of 126 features is collected for each candidate region. Three different feature groups are computed: intensity features, shape features and context features. The context features describe the position of the candidate region with respect to surrounding objects such as airways and lung boundaries. Classification of all candidate regions is performed in a two-stage approach, comparable to the solid nodule CAD system. In the first stage, a Linear Discriminant classifier (LDA) using only four features is used to remove a large amount of false positive candidate regions. This reduced the number of candidate regions in the training data set used in the paper by 66%. Then, in the second stage, a GentleBoost classifier using all 126 features and the posterior probability from the LDA classifier is used to classify all remaining candidate regions.

The training data set of the system consisted of 67 low-dose CT scans from the NELSON screening trial. Previous evaluation of the CAD system on 73 CT scans yielded a sensitivity of 73% at an average of only 1.0 FP/scan [6].

3.3 Combining the systems

Many different approaches can be used to combine CAD systems [14]. For example, a system could use a combination of the feature sets of both systems and design a new classifier to classify candidates from both sytems, or the system could simply merge the final output of both systems in an efficient way. To get a first impression of the combined performance of both CAD systems, we merged the final output of both systems. The CAD systems are operating independently and are set to operate at a fixed operating point. Then, solid nodule and GGN marks are combined. If two marks are within a distance of 10 mm of each other, the marks are considered to be marking the same nodule and the location is adjusted to the center of the two marks. In a CAD prototype workstation, three different marks will be shown: one for a finding detected by the solid nodule CAD, one for a finding detected by the GGN CAD and one for a finding detected by both systems. The solid nodule CAD is set to operate at a FP rate of 4.2 FP/scan (see 3.1, last paragraph) and the GGN CAD system is set to operate at 1.0 FP/scan (see 3.2, last paragraph).

4 Results

The prototype solid nodule CAD system found 323 markers; the ground glass nodule CAD system found 135 markers. When evaluating marker locations, 42 markers were found to be marking the same nodule. Consequently, this led to 281 markers originating from the solid nodule CAD only, 93 markers from the GGN CAD only and 42 markers which were detected by both CAD systems. In Fig. 1, examples of findings which were marked by both systems are presented.

5 Discussion and Conclusion

This study shows that the solid nodule CAD and GGN CAD systems have considerable overlap. Since a solid nodule CAD is probably able to detect the solid component of a GGN, we hypothesized that mainly ground glass nodules with a solid component will be found by both CAD systems. When inspecting the findings in Fig. 1, this hypothesis can be confirmed.

In the near future, we will consider more complex and efficient combination strategies. One could add more suspicion to a mark when it is found by two CAD systems. In addition, if a finding has a relatively low probability, but is found by both CAD systems, it might be worthwhile to also mark this finding.

In conclusion, this paper shows that there is overlap between the markers found by two prototype CAD systems for detection of GGNs and solid nodules, respectively. Combination of multiple prototype CAD system for detection of respectively GGNs and solid nodules seems feasible and could lead to a higher overall detection rate of lung nodules in chest CT scans.

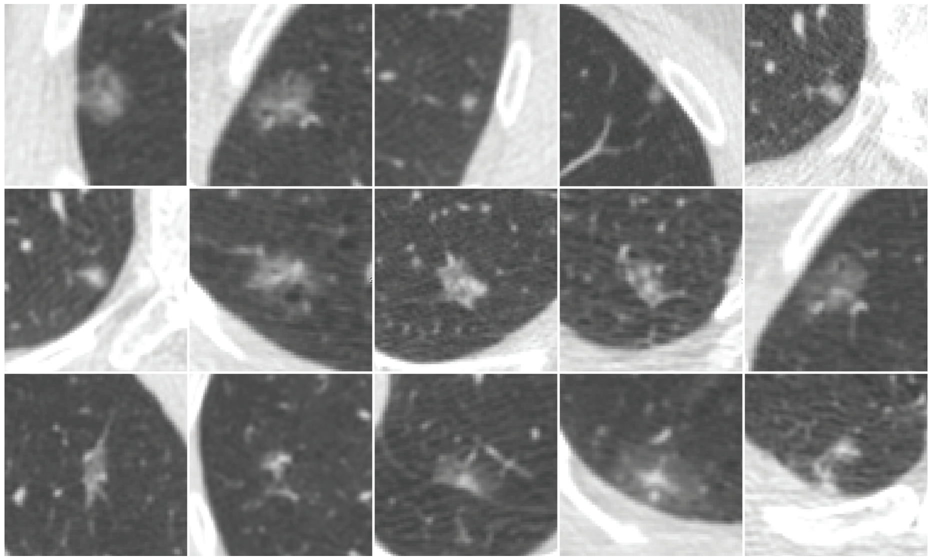

Fig. 1. Examples of nodules which were found by both the solid nodule CAD system and the GGN CAD system. All images are centered at the nodule, axial views of 45 × 45 mm and with a window level of -600/1600 HU. Many of these findings seems to be ground glass nodules with a solid component.

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