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Computer-aided detection of pulmonary nodules using dynamic self-adaptive template matching and a FLDA classifier

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ABSTRACT

Improving the performance of computer-aided detection (CAD) system for pulmonary nodules is still an important issue for its future clinical applications. This study aims to develop a new CAD scheme for pulmonary nodule detection based on dynamic self-adaptive template matching and Fisher linear discriminant analysis (FLDA) classifier. We first segment and repair lung volume by using OTSU algorithm and three-dimensional (3D) region growing. Next, the suspicious regions of interest (ROIs) are extracted and filtered by applying 3D dot filtering and thresholding method. Then, pulmonary nodule candidates are roughly detected with 3D dynamic self-adaptive template matching. Finally, we optimally select 11 image features and apply FLDA classifier to reduce false positive detections. The performance of the new method is validated by comparing with other methods through experiments using two groups of public datasets from Lung Image Database Consortium (LIDC) and ANODE09. By a 10-fold cross-validation experiment, the new CAD scheme finally has achieved a sensitivity of 90.24% and a false-positive (FP) of 4.54 FP/scan on average for the former dataset, and a sensitivity of 84.1% with 5.59 FP/scan for the latter. By comparing with other previously reported CAD schemes tested on the same datasets, the study proves that this new scheme can yield higher and more robust results in detecting pulmonary nodules.

1. Introduction

Lung cancer is one of the most aggressive human cancers, with a 5-year overall survival of 10–15% [1]. Previous studies show that if the pulmonary nodules can be detected at an early stage and immediately treated surgically, almost 90% of patients typically have a good prognosis with a 10-year survival [2]. In order to detect lung cancer early, thoracic computed tomography (CT) is applied as a screening and clinical examination imaging modality due to its non-invasiveness and superiority in detecting lung nodules and helping diagnosis of early lung cancers [3]. Thus, early detection of pulmonary nodules is important for effective treatment of lung cancer and improving prognosis of lung cancer patients. Each CT examination contains more than one hundred of images to be read and evaluated by radiologists [4]. Computer-aided detection (CAD) technology provides radiologists with a helpful "second opinion" to improve their detection of pulmonary nodules and their diagnostic performance in reading thoracic CT images [5].

In the past decade, many CAD technologies based automated pulmonary nodule detection methods were developed and tested. Based on different of algorithms in locating pulmonary nodules, these CAD methods roughly fall into two categories: template-matching based method and classifier based method.

In general, the template-matching based technology incorporates diverse empirical models of lung nodules to search nodules on CT scans. For example, Lee et al. [6] proposed a template-matching technique based on a genetic algorithm (GA) template matching (GATM) for detecting nodules existing within the lung area and then applied several rule based methods to remove false-positives (FPs). In particular, Osman et al. [7] proposed a three-dimensional (3D) template matching algorithm to detect suspected nodules. To incorporate temporal patterns of lung nodules, Jo et al. [8] proposed an automatic nodule registration method between baseline and follow-up chest CT scans and achieved 100% hit rate. In conclusion, the template-matching based method could apply different empirical models or geometric modules to establish nodule templates [9], achieving high sensitivity within an acceptable rate of false positives.

Whereas, the classifier based methods mainly depend on extracting features of suspected nodules and then employing one

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or several proper classifiers to detect pulmonary nodules. For example, Murphy et al. [10] analyzed the local image features of shape index and curvedness for delineation of nodule structures, and used two successive k-nearest-neighbor (KNN) classifiers to reduce false-positive rate. Tan et al. [12] proposed a novel feature-selective classifier based on genetic algorithm and artificial neural networks (ANNs). Choi et al. [13] proposed a novel pulmonary nodule detection system based on a genetic programming (GP) based classifier. Wang et al. [14] proposed a support vector machine (SVM) based on 3D-matrix patterns for detecting lung nodules. By comparing classifier based methods, it can be concluded that these approaches generally apply classifiers (SVM, ANN, KNN, etc.) [15–16] to discriminate nodules from non-nodules based on image features and gain good performance [17].

According to the analysis of two different approaches, we propose a 3D dynamic self-adaptive template matching method to roughly detect pulmonary nodules, and then use Fisher linear discriminant analysis (FLDA) classifier to remove the false-positive nodules (FPs). In this paper, we first describe the pulmonary nodule detection method (Section 2). The detection method mainly consists of three parts: preprocessing, rough detection of candidates, and reduction of FPs. Then we outline the experiments and results of this method, comparing with and evaluating against Lung Image Database Consortium (LIDC) and ANODE09 database (Section 3). Finally, we discuss the performance and limitations of this method, and then propose the prospects of CAD scheme for future works (Section 4).

2. Methods

Fig. 1 displays the workflow of the proposed pulmonary nodule detection method. Three basic image processing and feature analysis steps are contained in this flowchart and each unit is lined out with a dash line.

2.1. Preprocessing

To detect pulmonary nodules in CT scans, automatic segmentation of lung volume is the first step for preprocessing. Because lung parenchyma region contains air, its CT value is lower than its surrounding tissues. According to the rule of gray value distribution, lung parenchyma can be segmented with following steps.

First, left and right lung lobe is automatically segmented by using OTSU algorithm and 3D region growing algorithm. Based on previous study, two peaks are obvious in the histogram of the middle layer in each scan [18]. Thus, the middle layer image is segmented by using the OTSU threshold algorithm [19] and lung region in the middle layer is obtained. Then the left and right center points of the lung region in middle layer are selected as two seed points, and a 3D region growing algorithm is applied to segment left lobe and right lobe. Fig. 2 (d)–(f) shows the initial lung boundaries in the different slices.

Second, because the initial segmented lung regions may contain bronchi and leave out some juxta-pleural nodules, lung mask is further refined by using contour correction and boundaries repairing algorithm. Chain code algorithm is applied to repair the initial lung mask with the following three steps namely, 1) encode the boundary points in the initial lung mask and then identify the extreme points in the boundary, 2) calculate the distances of the neighborhood extreme points, 3) extract the refined parenchyma regions with the following rule. If the distance between two extreme points is less than the diameter threshold, the pair of points is jointed [14,18]. Fig. 2 (g)–(i) displays the repaired lung region in different slices.

Finally, lung parenchyma is obtained by masking initial CT scans with the lung lobe masks. Fig. 2 (j), (k) displays the initial and final 3D lung lobes.

The detection method is based on the isotropic hypothesis, but the resolution of CT scan is anisotropic in 3D spatial. To solve this problem, we first apply an isotropic interpolation process to generate isotropic scans. Here a bicubic interpolation algorithm along the axial direction is used to interpolate the images regardless of the actual axial resolution.

2.2. Rough detection

After lung segmentation, the suspicious nodules or nodular regions are detected by using the regions of interest (ROIs) extraction algorithm [20]. Since pulmonary nodules are often presented as regions with high gray value in CT images, the nodular regions can be extracted by using a thresholding algorithm at first. Assuming a threshold gray value T is selected to extract ROIs with lung parenchyma scans, then, all pixels with value greater than T are regarded as nodular pixels. But the gray value of pulmonary nodule is similar with other critical structures, such as blood vessel and bronchial. A simple thresholding method will produce too many false positive regions. So we need to remove the attached blood vessels and bronchial structures from the suspected nodules.

Since most pulmonary nodules are visualized as spherical opacities with diameter smaller than 30 mm in CT scans [21,22], in order to extract ROIs precisely, a multi-scale 3D dot filtering algorithm is utilized to locate ball likely structures and remove spurious ones [18,23].

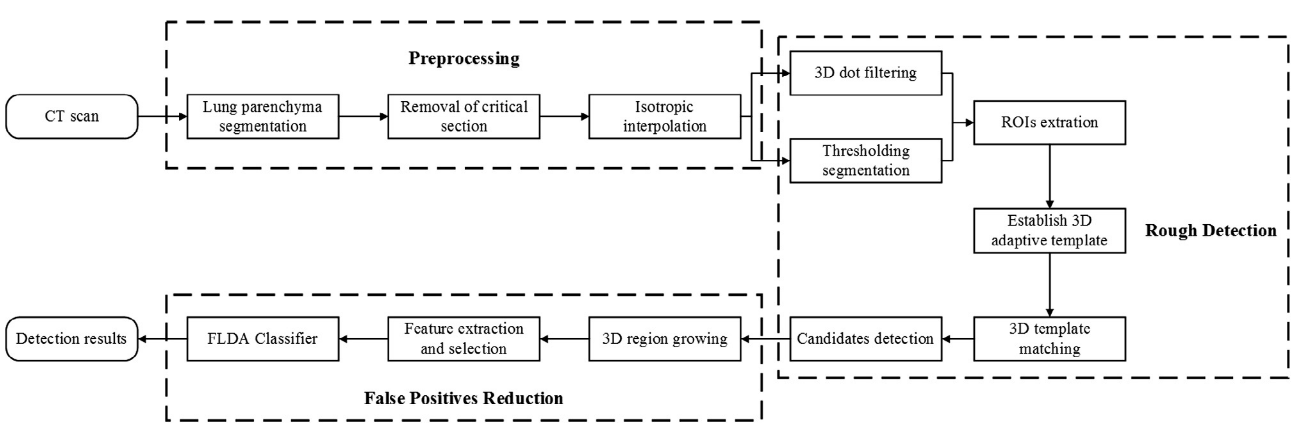

Fig. 1. Workflow of the proposed pulmonary nodule detection method.

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