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# Automated pulmonary nodule detection based on three-dimensional shape-based feature descriptor

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ABSTRACT

Computer-aided detection (CAD) can help radiologists to detect pulmonary nodules at an early stage. In pulmonary nodule CAD systems, feature extraction is very important for describing the characteristics of nodule candidates. In this paper, we propose a novel three-dimensional shape-based feature descriptor to detect pulmonary nodules in CT scans. After lung volume segmentation, nodule candidates are detected using multi-scale dot enhancement filtering in the segmented lung volume. Next, we extract feature descriptors from the detected nodule candidates, and these are refined using an iterative wall elimination method. Finally, a support vector machine-based classifier is trained to classify nodules and non-nodules. The performance of the proposed system is evaluated on Lung Image Database Consortium data. The proposed method significantly reduces the number of false positives in nodule candidates. This method achieves 97.5% sensitivity, with only 6.76 false positives per scan.

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## 1. Introduction

Lung cancer is the primary cause of cancer-related death in the world [1]. Most patients diagnosed with lung cancer are already at an advanced stage (40% are stage IV, 30% are stage III), and the current five-year survival rate is only 16% [2]. However, if defective nodules are detected at an early stage, the survival rate can be increased. In lung cancer research, computed tomography (CT) is one of the most sensitive methods for detecting pulmonary nodules, where a nodule is defined as a rounded and irregular opaque figure on a CT scan, with a diameter of up to 30 mm. However, though the early detection of pulmonary nodules is important in the treatment of lung cancer, each scan contains hundreds of images that must be evaluated by a radiologist, which is a tiring process. As such, the use of a computer-aided detection (CAD) system can provide an effective solution [3–6] by increasing the scanning efficiency and potentially improving nodule detection.

A nodule detection system generally consists of three steps: lung segmentation, nodule candidate detection, and false positive reduction [7,8]. In the literature, many researchers have presented a variety of methods for segmenting the lung volume from a pulmonary CT scan. Optimal thresholding is commonly used for segmenting the lung volume [3,9,10]. For this task, a fixed threshold value has also been used to segment the lung region [4,11,12]; after thresholding, the lung volume can be extracted from the segmented images using 3-D approaches. Paik et al. [4] and Retico et al. [11] used 3-D connectivity with a seed point in the initial lung region, and 3-D connected component labeling techniques have also been used to segment the lung volume without artifacts [10,12]. Ye et al. [13] proposed a 3-D adaptive fuzzy thresholding method to extract lung volume. At this stage, the

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extracted lung volume needs to be refined to include juxta-pleural nodules. Due to the complexity of these approaches, several methods for refining a lung mask have been presented. Generally, morphological dilation operators have been used to include juxta-pleural nodules [4,10], and a rolling ball algorithm has been applied for effective lung mask correction [3,11,12], whereby the rolling ball algorithm is equivalent to the combination of two fundamental morphological operations: erosion and dilation. Recently, a chain code representation over a lung mask was also proposed to correct the contours [13,14].

In the segmented lung volume, nodule candidates have been detected using various methods [15,16]. Multiple gray-level thresholds have been generally applied to the volumetric lung regions to identify nodule candidates [3,12,14,17]. Template-matching-based methods have also been extensively studied. Lee et al. [18] proposed a novel approach based on a genetic algorithm (GA) template matching (GATM) technique for detecting nodules within the lung area, with the GA applied to determine the target position in the observed image. Dehmeshki et al. [9] improved Lee's method, adding a shape-based approach to detect nodules with spherical elements. Osman et al. [19] applied a 3-D template-matching scheme by utilizing the third dimension of CT regions of interest, with the 3-D template being used to find structures with properties similar to nodules. Shape-based methods are also popular in nodule detection [20]. The surface normal overlap method [4,21] has been applied to colon polyp and lung nodule detection in helical CT images. Ye et al. [13] proposed a shape-based detection method by combining the shape index (local shape information) and "dot" features (local intensity dispersion information). This detection method provides a good structural descriptor for nodule detection. In addition, filtering-based methods have also been proposed to detect spherical objects as nodule candidates. Suzuki et al. [22] proposed a machine learning technique-based filter, known as the massive training artificial neural network (MTANN), which enhances the nodule intensity and eliminates various types of non-nodules. Retico et al. [11] described another automated procedure for selecting nodule candidates, based on a filter that enhances the shape of spherical objects. Suarez-Cuenca et al. [10] also developed a filtering method (3-D-iris filter) to characterize suspicious regions in the lung volume. Morphological approaches with convexity models [23] have been used to detect nodule candidates. Riccardi et al. [24] proposed a nodule detection method based on 3-D fast radial filtering and scale space analysis. Recently, mass-spring model-based segmentation and candidate detection methods have been proposed [25].

After nodule candidates detection, there are many false positives that require elimination. Over the past decade, several feature extraction methods and classification methods have been proposed to reduce false positives. Usually, the reported CAD systems segment the detected nodule candidates, and then features are extracted from the segmented nodule candidates. These features may be related to the geometry (volume, sphericity, radius of the equivalent sphere, maximum compactness, maximum circularity, and maximum eccentricity), gray-level (mean within the segmented object, standard deviation, and moments of gray-level), and gradient [12,14,26]. Finally, nodules are detected through various classifiers using the extracted feature vectors with a small number of false positives. To reduce false positives, rule-based filtering methods have been proposed [9,18,19]. Linear discriminant analysis (LDA) classifiers are generally used for nodule detection [3,10,12]. Suarez-Cuenca et al. [10] characterized the nodule candidates based on features extracted by an iris filter and morphological features. In this system, three classification functions are obtained by LDA. Recently, Messay et al. [12] proposed a sequential forward selection process to determine the optimum subset of features for two distinct classifiers: the Fisher linear discriminant classifier and the quadratic classifier. Furthermore, machine learning-based classification methods have also been used for false positive reduction. These methods are based on GAs [13], genetic programming [14], neural networks [17,25,27], and support vector machines (SVMs) [28,29]. Moreover, a neural approach for the classification of each single voxel of a nodule candidate was developed and implemented to reduce the number of false positives per scan [11]. Ye et al. [13] used a weighted SVM to classify nodule and non-nodule classes.

There are many CAD systems for detecting nodules, and these have different strengths and weaknesses. Table 1 gives a brief review of the three major steps in recent CAD systems; these systems will be compared with the proposed method.

In this paper, we propose a novel 3-D shape-based feature descriptor to detect pulmonary nodules. Due to the increasing availability of techniques for modeling, digitizing, and visualizing 3-D shapes, the demand for 3-D object recognition and retrieval is growing. Thus, several methods are proposed [30]. The extraction of feature descriptors for differentiation and recognition has an important role. The scale invariant feature transform (SIFT) has been popular over the last decade for 2-D images [31]. SIFT can extract salient points and feature descriptors in the most invariant way with respect to scaling, translation, orientation, affine changes, and illumination within images. However, SIFT is designed for and tested on 2-D images of 3-D objects. There are several extensions to higher dimensions, and Scovanner et al. proposed a fully orientation invariant 3-D SIFT [32]. Furthermore, the histogram of oriented gradients (HOG) is also popular for describing salient points on 2-D images of 3-D objects [33], and a 3-D extension of HOG has been proposed for 3-D object retrieval [34]. To describe local shape information for salient points on a 3-D object, 3-D SIFT [32] and 3-D HOG [34] feature descriptors have been proposed.

In reported CAD systems, researchers have applied geometric features, gray-level features, and gradient features to describe the characteristics of nodule candidates. These feature extraction methods require the nodule candidates to be segmented. It is difficult to accurately segment nodule candidates. Thus, we propose a novel feature descriptor that does not require segmentation. This is used to describe the characteristics of nodule candidates to detect pulmonary nodules. The proposed feature is calculated from surface elements that describe the local shape of the target object. These elements are obtained for every voxel of the target object through eigenvalue decomposition of the Hessian matrix. The

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