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Review

Automatic 3D pulmonary nodule detection in CT images: A survey

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ABSTRACT

This work presents a systematic review of techniques for the 3D automatic detection of pulmonary nodules in computerized-tomography (CT) images. Its main goals are to analyze the latest technology being used for the development of computational diagnostic tools to assist in the acquisition, storage and, mainly, processing and analysis of the biomedical data. Also, this work identifies the progress made, so far, evaluates the challenges to be overcome and provides an analysis of future prospects. As far as the authors know, this is the first time that a review is devoted exclusively to automated 3D techniques for the detection of pulmonary nodules from lung CT images, which makes this work of noteworthy value. The research covered the published works in the Web of Science, PubMed, Science Direct and IEEEXplore up to December 2014. Each work found that referred to automated 3D segmentation of the lungs was individually analyzed to identify its objective, methodology and results. Based on the analysis of the selected works, several studies were seen to be useful for the construction of medical diagnostic aid tools. However, there are certain aspects that still require attention such as increasing algorithm sensitivity, reducing the number of false positives, improving and optimizing the algorithm detection of different kinds of nodules with different sizes and shapes and, finally, the ability to integrate with the Electronic Medical Record Systems and Picture Archiving and Communication Systems. Based on this analysis, we can say that further research is needed to develop current techniques and that new algorithms are needed to overcome the identified drawbacks.

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Contents

1. Introduction

Lung cancer is the leading cause of cancer deaths in the world [1]. In developed countries, patients diagnosed with this pathology have a five-year survival rate between 10 and 16%. This occurs because about 70% of lung cancer cases are diagnosed in advanced stages, preventing effective treatments. However, in cases where lung cancer is diagnosed in early stages, the five-year survival rate increases to 70% [2].

Computerized tomography (CT) has become the most sensitive imaging modality for the detection of small lung nodules, particularly since the introduction of helical multislice technology [3]. More recently, one of the hopes to change the scenario of late diagnosis has been conducted by monitoring programs with low-dose CT, particularly applied to risk groups such as smokers [4].

After identifying a pulmonary nodule through CT, the physician is asked about its malignancy. During the investigation, the radiologist must list the diagnostic possibilities and offer a result based on the analysis of the nodule morphology and clinical context. This diagnosis may have no treatment, no follow up, or may recommend surgical resection. However, it should always seek a cost benefit trade-off analysis of treatment strategies by not allowing a potentially malignant nodule to continue evolving, by limiting unnecessary invasive investigations and radiation from repeated CT scans as well as containing patient anxiety. The chosen strategy should follow traditional recommendations and incorporate the recent extensive and fast changing research found in the literature. The nodule imaging features and the role of the radiologist are essential to the definition of this diagnosis [5].

In general, a lung nodule is defined as a focal opacity with a diameter between 3 and 30 mm [6]. The term "micronodule" is reserved for opacities less than 3 mm in diameter and the term "mass" is used for opacities which are larger than 30 mm. The accuracy in calculating the nodule diameter is critical because the nodule size is related to malignancy. For example, the percentage of malignancy in the End-Use Load and Consumer Assessment Program (ELCAP) database [7] is 1% for nodules smaller than 5 mm, 24% for nodules between 6 and 10 mm, 33% between 11 and 20 mm and 80% for nodules with a diameter up to 20 mm [8]. In asymmetric or non-spherical nodules, errors may occur when calculating the diameter. If the nodule is too small, the measures should be calculated after maximizing the image size. As a result of inaccuracies in the diameter measured manually, automated methods for measuring nodule diameters have been developed [9].

However, despite initiatives to promote early diagnosis, physicians do not always make the best use of the data acquired from the imaging devices [10,11]. Limitations of the human visual system, insufficient training and experience, factors such as fatigue and distraction may contribute to the inefficient use of available information [12–14]. In this scenario, automated techniques of image analysis processing can be applied as medical aid tools in an effort to minimize these difficulties. The central idea of this approach is to modify the displayed image, highlighting the possible existing abnormalities for radiologists [15].

Since 1980, several attempts have been made to develop a system able to detect, segment [16,17] and diagnose pulmonary nodules from CT scans. As the appearance of pulmonary nodules varies according to its type, malignancy or not, size, internal structure and location, nodule detection and segmentation have become a major challenge, often involving methodologies of various levels, each handling a particular aspect of the problem [18].

These systems are known as computer-aided diagnosis systems (CAD) and go beyond just image processing in order to provide specific information about the lesion that can assist radiologists in the diagnosis. However, image processing alone is not able to solve problems such as fatigue, distraction or limitations in training [15].

CAD systems can be divided into two systems: detection system (CADe) and diagnostic system (CADx). The goal of a CADe system is to identify regions of interest in the image that can reveal specific abnormalities and alert physicians to