Progress in Computer-aided Diagnosis of Lung Nodules based on CT Images

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Abstract: The objective of this study is to review the research progress of computer-aided diagnosis of pulmonary nodules based on CT images. This is done in order to address the challenges posed by the increasing incidence and difficulty of diagnosis of pulmonary nodules. Through an in-depth analysis of the key technologies, algorithms and application cases in the diagnosis of pulmonary nodules, we sought to identify how computer technology can be used to improve the accuracy and efficiency of diagnosis. The study found that CT images have the advantages of high resolution and multi-dimensional reconstruction in the detection of pulmonary nodules. However, interpreting CT images still requires specialized medical knowledge. Computer-aided diagnosis technology can assist doctors to identify lung nodules more accurately, especially for nodules with similar density to the surrounding tissue. This can improve the sensitivity and specificity of diagnosis. In conclusion, the computer-aided diagnosis system based on CT images provides substantial support for the accurate diagnosis of pulmonary nodules, which is beneficial for the improvement of patient health management and the formulation of treatment plans.

Keywords: CT Images; Lung Nodules; Computer-Aided Diagnosis; Research Progress

1. Introduction

Lung nodules are a common lung disease. Early and accurate diagnosis of the disease is important to protect the patient's health and life safety. However, due to the variety of morphology and size of lung nodules, the traditional manual reading of the film in the diagnostic process has a variety of limitations. With the continuous development of computer technology, the computer-aided diagnosis system based on CT images has been gradually introduced into the diagnosis of lung nodules. This paper presents a summary of the research progress in the field of computer-aided diagnosis of lung nodules based on CT images. It includes an overview of the key technologies, algorithms, and application cases that have been developed to improve the diagnosis of lung nodules.

2. Pulmonary Nodules, Overview of Computer-Aided Diagnostic Techniques

2.1 Overview of Lung Nodules

Lung nodules are a common type of lung lesion, including many subtypes. The size, shape, and growth rate of different types of lung nodules vary. By analyzing this information, clinicians can determine the nature of the lung disease. In recent years, with the rapid development of medical imaging technology, especially the wide application of computed tomography (CT) technology, the detection rate of lung nodules has been greatly improved.

2.1.1 Definition of lung nodule

Lung nodules are defined as lesions in the lungs, typically less than 3 centimeters in diameter, round or round-like in shape, with clear borders, and varying in size, shape, and density from nodule to nodule. Lung nodules may arise for a number of reasons, including

inflammation of the lungs, tuberculosis, benign tumours and malignant tumours, among others. The degree of harm associated with different types of lung nodules varies, as does the efficacy of the treatment methods employed. Consequently, an accurate diagnosis of the type of lung nodule is of great importance for the development and optimization of the treatment plan.

Imaging techniques are currently one of the main diagnostic methods for the diagnosis of lung nodules, with computed tomography (CT) scanning being a particularly useful tool. This method is able to clearly display lung structures, including the lung parenchyma, blood vessels, bronchi, and pleura, as well as other tissues. By observing the CT images, clinicians can identify tiny nodular lesions in the lungs and thus determine their nature. Consequently, a definitive diagnosis based on visual observation alone is often challenging, as different types of lung nodules exhibit varying morphologies and densities, and some may exhibit a lack of definition of the boundary with surrounding tissues. Hu et al. [1] demonstrated that computer-aided diagnosis is a diagnostic technique developed in response to this background, with the objective of enhancing the accuracy of diagnosis.

2.1.2 Classification of lung nodules

In terms of etiology, lung nodules are classified into two main categories: benign and malignant. Benign nodules are primarily caused by benign lesions, such as inflammation and tuberculosis in the lungs. Malignant nodules, on the other hand, are mainly caused by malignant tumors, such as lung cancer, among others. Pathological features of lung nodules are further classified into three categories: solid, partially solid, and ground-glass nodules. In terms of pathological features, lung nodules are classified into solid nodules, partially solid nodules, and ground-glass nodules, among others. The imaging characteristics of different nodule types vary.

2.2 CT Images in the Diagnosis of Lung Nodules

He et al. [2] demonstrated that current computed tomography (CT) images have become an indispensable tool in the diagnosis of lung nodules. These images possess high resolution and multilayer reconstruction, enabling clinicians to view the morphology, size, and location of the lung nodules and their relationship with the surrounding tissues through CT images. This allows for the determination of the type of lung nodule condition.

2.2.1 Development of CT technology

The evolution of CT technology has encompassed a multitude of advancements, from the initial plain CT to the subsequent spiral CT, high-resolution CT, and the latest low-dose CT, among others. While plain CT is sufficient for demonstrating the fundamental structure of the lungs, it is important to note that its resolution tends to be inferior, its scanning speed is slower, and its capacity to detect minute nodules is limited. In contrast, spiral CT technology markedly enhances scanning speed and image quality through continuous rotational scanning, thereby enabling physicians to more accurately assess lung lesions. Furthermore, high-resolution CT technology further improves the resolution of the images, allowing even the smallest structural changes in the lungs to be clearly visualized. Low-dose CT technology, on the other hand, is a relatively recent technology that has been promoted in recent years. By optimizing scanning parameters and adopting advanced image reconstruction algorithms, this technology can reduce the radiation dose while maintaining high image quality, thus reducing the risk of radiation exposure during examinations.

2.2.2 Strengths and weaknesses of CT technology in the detection of pulmonary nodules

The advantages of CT technology in the detection of lung nodules are primarily reflected in its high resolution, particularly the three-dimensional reconstruction technology that has been applied in recent years. This technology greatly improves the detection ability of CT scans. Xiao et al. [3] demonstrated that high resolution can ensure the clarity of the display of small lesions in the lungs, which can help to diagnose the lung nodule condition at an early stage. Three-dimensional reconstruction technology, however, can assist physicians in viewing information such as the morphology of lung nodules from multiple perspectives, thereby enabling the accurate determination of the condition of lung nodules. Nevertheless, there are certain limitations associated with CT

technology in the detection of lung nodules. These limitations are primarily reflected in the difficulty of CT technology to accurately determine some of the nodules with similar density to the surrounding tissues, which results in a certain limitation of the detection rate of this technology. In particular, the interpretation of CT images requires specialized medical knowledge. Lv et al.[4] demonstrated that the patient's medical history, clinical manifestations, and other auxiliary examination results must be considered when using CT images to diagnose lung nodules in order to enhance the accuracy of diagnosis.

2.3 Computer-Aided Diagnosis in the Recognition of Pulmonary Nodules

2.3.1 Shortcomings of traditional diagnostic methods

In the traditional diagnosis of lung nodules, physicians rely primarily on visual observation to diagnose the nodules. This is achieved by analyzing information such as nodule morphology, density, and boundaries in CT images. However, this approach is highly subjective, as it is affected by a variety of factors, including the physician's experience level, fatigue, and image quality. Different physicians may interpret the same CT image differently, which can lead to discrepancies in the diagnosis. This is particularly pertinent in light of the growing number of patients undergoing imaging procedures and the exponentially increasing volume of images physicians are required to review. The prolonged and repetitive nature of interpreting a substantial number of CT images can precipitate physician fatigue, which may compromise the accuracy of the diagnosis. A study by Pei et al. [5] demonstrated that certain small pulmonary nodules may be inadequately discernible in imaging, thereby intensifying the diagnostic challenge.

2.3.2 Advantages of computer-aided diagnosis in the identification of pulmonary nodules

Computer-aided diagnostic technology primarily identifies lung nodules in CT images through computer image processing and analysis methods, which offers multiple advantages. Primarily, computer-aided diagnostic technology can enhance diagnostic accuracy, enabling the automated extraction of nodule characteristics, such as advanced image processing methods are employed to extract morphological, density, and textural characteristics of nodules, which are then compared with a predefined diagnostic model. This enables the accurate determination of disease, circumventing the influence of subjective factors and enhancing the reliability of diagnosis. Secondly, traditional diagnostic methods require doctors to spend a significant amount of time reading films, which can be fatiguing. In contrast, computer-aided diagnostic technology can automatically complete the majority of the work, with doctors only needing to review and confirm the results. This effectively reduces the workload of the doctor and helps to shorten the diagnostic time.

3. Computer-Aided Diagnosis of Lung Nodules based on CT Images

3.1 Image Pre-Processing Techniques

In the field of computer-aided diagnosis of lung nodules based on CT images, image preprocessing technology represents a crucial component, as it plays a pivotal role in enhancing image quality and improving the visibility of the target area.

3.1.1 Noise suppression and image enhancement techniques

Computed tomography (CT) images are frequently corrupted by various types of noise during the acquisition and transmission of information. These include electronic noise, ray scattering, and other forms of interference. Such noise can reduce the image quality and potentially obscure small lesions, such as lung nodules, which may result in misdiagnosis. Noise suppression technology represents a solution to this problem. Commonly employed noise suppression methods include median filtering, Gaussian filtering, and others, which can effectively reduce the impact of noise on the diagnosis.

Image enhancement techniques are employed primarily to enhance the contrast between lung nodules and surrounding tissues, thereby rendering lung nodules more conspicuous and facilitating the analysis of images by medical professionals. Commonly employed image enhancement techniques include histogram equalization

and contrast stretching, which can markedly enhance the visual quality of the images, thereby enhancing the accuracy of diagnosis.

3.1.2 Image segmentation and edge detection techniques

The objective of image segmentation is to differentiate lung nodules within the lung structure for subsequent processing. Li et al. [6] demonstrated that lung nodules necessitate preprocessing through image segmentation techniques due to their diverse morphology, size, location, and adhesion to surrounding tissues. The prevailing image segmentation methodologies include threshold-based segmentation, region-based segmentation, and edge-based segmentation.

Edge detection is a technique employed in the extraction of edge information from lung nodules. The edge is typically defined as the region exhibiting the greatest degree of gray scale change within an image. Through the application of edge detection technology, clinicians can obtain the contour, shape, and other characteristics of lung nodules, which can serve as a foundation for subsequent classification and identification. Currently, the most prevalent edge detection methods include the Sobel operator, Canny operator, and others.

3.1.3 3D reconstruction and visualization techniques

Three-dimensional reconstruction technology employs multiple two-dimensional computed tomography (CT) images to generate a three-dimensional representation of the lungs, enabling physicians to observe the morphology, location, and spatial relationship of lung nodules from multiple angles. In contrast, visualization technology presents the 3D reconstruction results in a manner that is intuitive to clinicians, thus aiding in the accurate determination of the nature of lung nodules. Chen et al. [7] demonstrated that the utilization of three-dimensional reconstruction and visualization technology markedly enhances the precision of diagnosis. Clinicians are able to adjust the observation angle and rotate and zoom by employing this technology, thereby facilitating a more comprehensive comprehension of the characteristics of lung nodules and the relationship between the surrounding tissues. This, in turn, enables the accurate determination of the patient's condition.

3.2 Feature Extraction Mthods

3.2.1 Morphology-based feature extraction methods

Morphology-based feature extraction methods primarily employ image processing techniques, such as edge detection and region growing, to extract contour and regional information from images of lung nodules. For instance, morphological parameters such as area, circumference, roundness, and so forth, can be calculated to describe the shape characteristics of nodules, which can then be used to determine the benign or malignant nature of lung nodules. Leng et al. [8] demonstrated that morphological-based feature extraction methods possess the advantages of being intuitive and easy to understand. However, due to the diverse morphologies of lung nodules and their susceptibility to the surrounding tissues, it is often challenging to accurately assess them solely based on morphological features. Consequently, it is essential to integrate these features with other techniques to achieve a comprehensive evaluation.

3.2.2 Texture-based feature extraction methods

Texture-based feature extraction methods primarily reflect the texture information of lung nodules by calculating texture features such as the gray scale covariance matrix and wavelet transform of the image. In clinical practice, it has been demonstrated that the internal structure and heterogeneity of lung nodules can be identified by analyzing texture features to determine the type of lung nodule. In a study by Takenori K et al. [9], it was found that texture features provide more information about lung nodules than morphological features. However, the computational process of this method is relatively complex, which limits its generalizability.

3.2.3 Deep learning based feature extraction methods

Deep learning models primarily comprise techniques such as convolutional neural networks (CNNs), which are capable of automatically learning the mapping relationship between raw images and high-

level features, thereby enabling the extraction of features of lung nodules. Deep learning-based feature extraction methods are adept at handling large-scale image data and also facilitate the automatic optimization of the feature extraction process, which in turn enhances the efficacy of computer-aided diagnosis of lung nodules.

4. Progress in Computer-Aided Diagnosis of Lung Nodules based on CT Images

In the field of lung nodule computer-aided diagnosis, deep learning technology represents the current research focus. The technical level of lung nodule detection algorithms has been significantly improved, and the current commonly used algorithms include models such as convolutional neural network (CNN) and Faster R-CNN, which are able to automatically learn the features in the image and accurately locate the position and size of lung nodules. In overseas research institutions, there is a great deal of activity in the field of lung nodule detection algorithms. The construction of large-scale CT image datasets and the continuous optimization of deep learning models have led to a significant improvement in the detection ability of lung nodules. In addition, these research institutions are engaged in the active exploration of a variety of techniques to enhance the performance of detection algorithms. These include multi-scale feature fusion, contextual information utilization, and so on. A considerable quantity of CT image data is also included in numerous research organizations in China, where the detection algorithms are studied in depth based on these data. Liu et al. [10] demonstrated that some research teams have markedly enhanced the level of diagnostic technology by combining the experience of clinicians, integrating medical knowledge with deep learning technology, and developing a greater number of lung nodule detection algorithms that meet clinical needs. In the future, deep learning technology and multimodal data fusion technology will also become important elements of computer-aided diagnosis of lung nodules based on CT images.

5. Conclusion

In conclusion, computer-aided diagnosis technology based on CT images plays a pivotal role in the diagnosis of lung nodules. Moreover, this technology has yielded significant research outcomes, particularly in the domains of image preprocessing, feature extraction, and classifier design. These techniques facilitate the automated detection of lung nodules and enhance the accuracy and efficiency of diagnosis. Nevertheless, due to the inherent complexity of lung nodules, the current computer-aided diagnosis system still exhibits certain limitations. Looking ahead, with the continuous advancement of computer technology, the computer-aided diagnosis technology of lung nodules based on CT images will also usher in a broader development prospect.

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