IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ∺ Peer-reviewed & Refereed journal ∺ Vol. 15, Issue 4, April 2026

DOI: 10.17148/IJARCCE.2026.15413

Detection and Prevention of Lung Diseases Using Convolutional Neural Networks: A Comprehensive Review

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Abstract: Respiratory diseases such as pneumonia, tuberculosis, chronic obstructive pulmonary disease, and lung cancer continue to pose a major threat to global public health. Accurate and early diagnosis remains a critical challenge due to inter-observer variability, radiologist fatigue, and limited access to expert interpretation, particularly in resource-constrained settings. Recent advances in deep learning, specifically convolutional neural networks (CNNs), have enabled automated analysis of chest radiographs and computed tomography scans with accuracy approaching and, in some cases, exceeding expert-level performance. This paper presents a detailed review of CNN-based methodologies for lung disease detection and prevention. The review synthesizes theoretical foundations, learning paradigms, benchmark datasets, state-of-the-art architectures, performance metrics, and prevention-oriented applications such as risk stratification and opportunistic screening. Key challenges related to data bias, explainability, regulatory compliance, and real-world deployment are discussed, along with future research directions toward robust and ethically deployable AI-driven diagnostic systems.

Keywords: Convolutional Neural Networks, Lung Disease Detection, Chest X-ray, Deep Learning, Medical Imaging, Preventive Healthcare

I. INTRODUCTION

Pulmonary diseases represent one of the leading causes of morbidity and mortality worldwide. Conditions such as pneumonia, tuberculosis (TB), chronic obstructive pulmonary disease (COPD), and lung cancer account for millions of deaths annually and place a substantial burden on healthcare systems. Early diagnosis is a decisive factor in improving patient outcomes; however, conventional diagnostic workflows depend heavily on radiological imaging interpretation, which is subject to human error and variability.

Chest radiography (CXR) and computed tomography (CT) scans are the most commonly employed imaging modalities for lung disease assessment due to their non-invasive nature and widespread availability. Despite their clinical utility, interpretation of these images requires extensive expertise, and subtle pathological manifestations are often overlooked, particularly in high-volume clinical environments. The global shortage of trained radiologists further exacerbates diagnostic delays, especially in low- and middle-income regions.

Artificial intelligence (AI) has emerged as a transformative solution to these challenges. Deep learning models, particularly CNNs, can automatically learn hierarchical feature representations from raw medical images, enabling scalable and consistent diagnostic support. Beyond detection, AI systems can contribute to disease prevention by facilitating early screening, risk prediction, and clinical decision support.

II. DEEP LEARNING FRAMEWORK FOR MEDICAL IMAGING

Convolutional neural networks are specifically designed to process grid-structured data such as images. Unlike traditional machine learning techniques that rely on handcrafted feature extraction, CNNs enable end-to-end learning by automatically discovering discriminative features directly from pixel intensities.

A typical CNN architecture consists of convolutional layers that apply learnable filters to extract spatial features, pooling layers that reduce dimensionality and enhance translational invariance, nonlinear activation functions such as the rectified

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linear unit (ReLU), and fully connected layers that perform classification. Early layers capture low-level patterns such as edges and textures, whereas deeper layers encode higher-level semantic information associated with pathological abnormalities.

Transfer learning has become a cornerstone of medical image analysis due to the scarcity of large, labeled medical datasets. By fine-tuning models pretrained on large-scale datasets such as ImageNet, researchers can leverage previously learned visual representations and adapt them to lung disease detection tasks. Architectures such as VGG16, ResNet50, and DenseNet121 are widely adopted due to their strong generalization capabilities and proven performance.

III. DATASETS FOR LUNG DISEASE DETECTION

The performance of CNN-based diagnostic systems is strongly influenced by the quality, diversity, and scale of training data. Several public datasets have become benchmarks for lung disease research.

The NIH ChestX-ray14 dataset comprises over 112,000 frontal chest radiographs annotated for 14 thoracic pathologies. Although labels are derived using natural language processing of radiology reports and may contain noise, the dataset remains foundational for large-scale multi-label classification research. Class imbalance is a notable challenge, as normal cases dominate the dataset.

For lung cancer detection, the LUNA16 dataset provides expertly annotated CT scans focusing on pulmonary nodules. The volumetric nature of CT data enables three-dimensional analysis, preserving spatial context that is critical for distinguishing malignant nodules from benign anatomical structures. Additional datasets targeting tuberculosis and pneumonia further support disease-specific model development.

IV. STATE-OF-THE-ART CNN ARCHITECTURES

Dense convolutional networks, particularly DenseNet121, have demonstrated state-of-the-art performance in pneumonia detection by promoting feature reuse and improving gradient flow. CheXNet, a DenseNet-based model, achieved radiologist-level performance on chest X-ray benchmarks, highlighting the feasibility of AI-assisted diagnosis.

Residual networks such as ResNet50 address vanishing gradient issues through skip connections, enabling stable training of deep architectures. EfficientNet and MobileNet architectures emphasize parameter efficiency and computational scalability, making them suitable for deployment in resource-constrained or edge environments.

V. PREVENTION-ORIENTED AI APPLICATIONS

Recent research has expanded the role of AI beyond disease detection toward prevention and risk stratification. Opportunistic screening models can estimate cardiovascular risk, biological lung age, or long-term mortality from routine chest X-rays, enabling early lifestyle or pharmacological interventions.

In chronic respiratory conditions such as COPD, AI-driven models can predict disease exacerbations and mortality risk by analyzing longitudinal imaging data and clinical metadata. Such predictive capabilities support proactive patient management and personalized treatment planning.

VI. CHALLENGES AND FUTURE DIRECTIONS

Despite significant progress, several challenges hinder widespread clinical adoption of AI-based lung disease diagnostic systems. Dataset bias and lack of external validation can limit generalization across populations and imaging devices. Regulatory compliance and ethical considerations require AI systems to function strictly as clinical decision support tools.

Future research directions include multimodal learning frameworks that integrate imaging data with electronic health records, as well as federated learning approaches that enable privacy-preserving collaboration across healthcare institutions.

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VII. CONCLUSION

CNN-based approaches have fundamentally transformed lung disease analysis and hold substantial promise for preventive healthcare. By combining robust architectures, diverse datasets, and explainable decision support mechanisms, AI-driven systems can enhance diagnostic accuracy and enable early intervention.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the valuable guidance and support provided by their project guide, Ms. Pradnya Meshram, Department of Artificial Intelligence and Data Science, Priyadarshini College of Engineering, Nagpur.

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