PulmoLens: A Framework Combining Visual Reasoning for Accurate Chest Disease Diagnosis

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Abstract: Accurate interpretation of chest X-ray images is essential for early detection of pulmonary diseases such as pneumonia, COVID-19, and tuberculosis. However, manual diagnosis is time-consuming and dependent on expert radiological knowledge, which may not be consistently available in all healthcare environment. This paper presents PulmoLens, an explainable artificial intelligence framework that leverages a Convolutional Neural Network(CNN) for automated chest disease classification while integrating Gradient-weighted Class Activation Mapping(Grad-CAM) to provide visual explanations for model predictions. The system enhances clinical trust by highlighting disease-relevant regions in X-ray images and supports multilingual interpretation of diagnostic results and medical reports.

Keywords: *Chest X-ray Analysis, Grad-CAM, Deep Learning, DenseNet, Medical Imaging, Multilingual Diagnosis, Explainable AI.*

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I. INTRODUCTION

Chest X-ray imaging remains one of the most commonly used diagnostic modalities for detecting lung-related diseases due to its low cost, fast acquisition, and widespread availability. Conditions such as pneumonia, tuberculosis, and viral infections like COVID-19 exhibit overlapping visual patterns, making accurate interpretation challenging even for experienced radiologists. The growing volume of medical imaging data and the shortage of trained professionals further increase the risk of delayed diagnosis and diagnostic inconsistency, particularly in resource- limited regions. These challenges highlight the necessity for intelligent automated systems that can assist clinicians by offering fast and reliable diagnostic insights.

Recent advancements in deep learning, particularly Convolutional Neural Networks(CNNs), have shown significant success in medical image classification tasks. However, many high-performing models function as black boxes, limiting their adoption in clinical practice due to a lack of transparency. PulmoLens addresses this limitation by combining CNN-based disease classification with Grad-CAM based visual explanations that highlight regions influencing model predictions. Additionally, the system incorporates multilingual support to translate diseaseexplanations and reports into multiple languages, improving accessibility and patient understanding. By integrating accuracy, explain ability, and inclusivity, PulmoLens aims to enhance diagnostic confidence and support effective clinical decision-making.

In addition to improving diagnostic efficiency, modern medical imaging systems must ensure transparency and ease of interpretation to be safely adopted in clinical environments. Healthcare professionals often require not only accurate predictions but also clear reasoning behind automated decisions to validate outcomes against clinical knowledge. PulmoLens is designed with this requirement in mind by integrating explainable artificial intelligence techniques that visually demonstrate how diagnostic conclusions are derived from chest X-ray images. By coupling visual interpretability with multilingual textual explanations, the system bridges the gap between advanced deep learning models and practical medical usability.

II. RELATED WORK

Recent advances in medical imaging and artificial intelligence have led to the development of intelligent diagnostic systems that assist clinicians in interpreting chest X-ray images more effective and more efficiently.

Bhuvaneswari and Thangamuthu presented a comprehensive review of deep learning-based diagnostic frameworks, highlighting how the integration of convolutional neural networks(CNNs), medical image preprocessing, and visualization tools significantly improves

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diagnostic accuracy and decision speed. Their study emphasized the growing role of explainable AI techniques, such as attention mapping, to enhance clinical trust and transparency in automated systems[1].

In 2025, Dhanalakshmi proposed an AI-driven medical imaging platform that combines disease classification with contextual clinical explanations. Their framework demonstrated that integrating and confidence scoring, and patient friendly descriptions improves accessibility and interpretability, particularly in resource limited healthcare settings. The authors also highlighted the importance of fall back mechanisms for report generation[2].

Similarly, Chinnaswamy introduced a cloud-enabled chest X-ray analysis system capable of detecting multiple pulmonary abnormalities using DenSetNet architectures. Their approach incorporated real-time image upload, automated prediction, and clinician alerts, enabling faster triage and early diagnosis. The inclusion of visualization overlays helped bridge the gap between model predictions and clinical understanding[3].

Chowdhuri explored the integration of hardware-assisted imaging workflows with AI-based diagnostic software. Their work focused on combining imaging devices with application-level intelligence to automate image acquisition, preprocessing, and disease inference. By minimizing manual intervention, the system addressed usability challenges commonly faced in high-pressure clinical environments[4].

More recently, Jeyanti proposed a secure, network-optimized framework for medical report transmission using advanced encryption and low-latency routing techniques. Their study demonstrated that ensuring data integrity and secure delivery of AI-generated diagnostic reports increases clinician confidence and supports large-scale deployment in hospital networks. The inclusion of standardized medical explanations was shown to enhance collaboration between radiologists and primary care physicians[5].

Collectively, these studies indicate a shift toward comprehensive, AI-assisted diagnostic platforms that extend beyond simple disease classification. However, many existing systems still lack integrated explainability, multilingual accessibility, and seamless report generation. The proposed PulmoLens AI system addresses these limitations by unifying deep learning-based multi-disease detection, Grad-CAM visual explanations, multilingual clinical interpretations, and automated PDF report generation within a single framework. This holistic design improves usability, transparency, and deployability, making it suitable for real-world clinical adoption.

III. PROPOSED FRAMEWORK

A. System Overview

The PulmoLens AI system is designed as an intelligent, end-to-end medical imaging platform for automated chest X-ray analysis and clinical decision support. The framework integrates deep learning-based disease detection with explainable visualization and multilingual reporting to assist healthcare professionals in early diagnosis and interpretation. The system follows a modular client-server architecture, where the frontend interface handles user interaction and visualization, while the backend manages model inference, data processing, and report generation.

The backend is implemented using the Flask framework, enabling light weight RESTful communication between the user interface and the AI engine. A pretrained DenseNet121 convolutional neural network serves as the core diagnostic model, capable of identifying multiple pulmonary conditions from chest X-ray images. To enhance clinical transparency, the framework integrated

Grad-CAM (Gradient-weighted Class Activation Mapping.), which highlights disease-relevant and reports, ensuring accessibility for users across different linguistic backgrounds. The overall architecture is optimized for real-time analysis, scalability, and deployment in both clinical and resources-constrained environments.

B. Key Functional Modules

The PulmoLens AI framework consists of several tightly integrated functional modules, each addressing a critical aspect of the diagnostic workflow. The image acquisition and preprocessing module allows users to upload chest X- ray images in standard formats. Uploaded images undergo resizing, normalization, and grayscale-to-RGB conversion to ensure compatibility with the deep learning model.

The AI inference module performs automated disease prediction using the trained DenseNet121 network. The model outputs probability scores for each supported lung condition, enabling confidence-based interpretation rather than binary classification. To improve trust and explainability, the Grad-CAM visualization module generates heatmaps that overlay on the original X-ray, visually indicating regions that influenced the model’s decision.

To address language barriers in healthcare, the multilingual explanation module dynamically adapts disease descriptions and clinical interpretations based on the user selected language. This module either retrieves predefined medical explanations or applies automated translation mechanisms to ensure clarity and consistency across languages. Complementing this, the report generation module compiles predictions, confidence scores, timestamps, and explanations into a structured PDF medical report, suitable for clinical documentation and patient communication.

All diagnostic records, including uploaded images and analysis metadata, are managed through the database management module, enabling traceablility and future reference. Together, these modules form a cohesive pipeline that transforms raw medical images into actionable, interpretable clinical insights.

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C. Visual Overview

The architectural workflow of the PulmoLens AI system is illustrated Fig.1, depicting the flow from image upload to diagnostic output. User interaction begins at the frontend, where chest X-ray images are submitted to the backend server. The backend routed the image through preprocessing, AI-based disease classification, and Grad- CAM visualization modules in parallel. The results are then enriched with multilingual explanations and consolidated into a comprehensive diagnostic response.

The framework is designed such that visualization, prediction, and reporting processes operate concurrently, minimizing response time while maximizing interpretability. By combining automated diagnosis with explainable AI and multilingual reporting, PulmoLens AI functions not only as a detection tool but also as a clinical decision-support system. This integrated design enhances usability, transparency, and real-world applicability, positioning the proposed framework as a robust solution for modern medical imaging workflows.

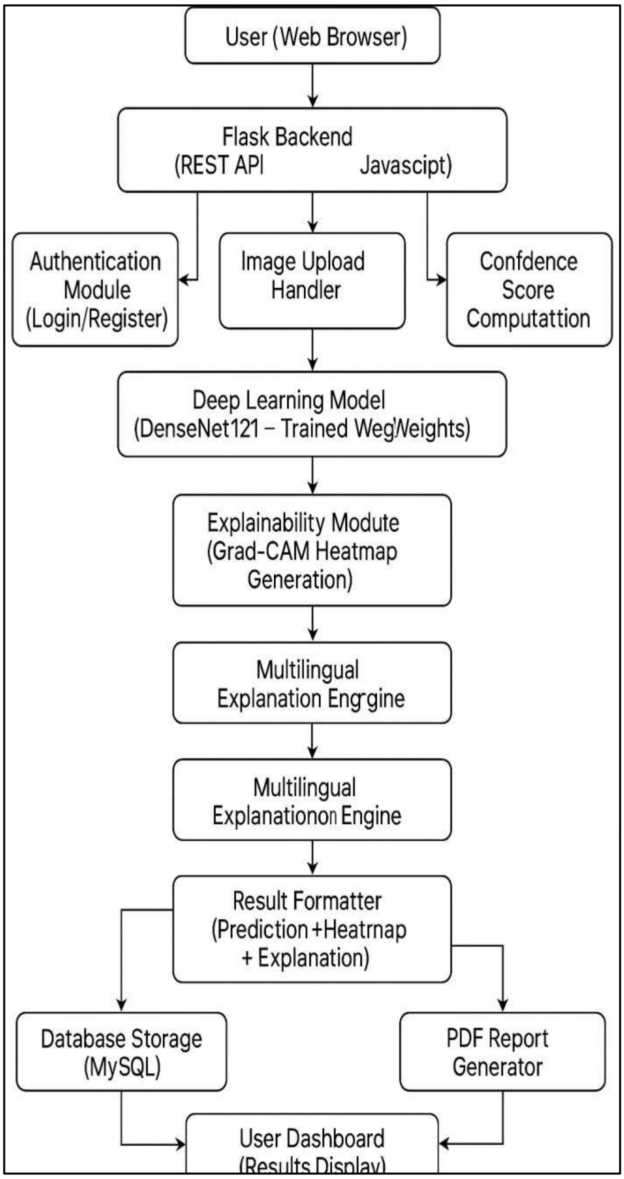

Fig.1 System Architecture Block Diagram

IV. METHODOLOGY AND IMPLEMENTATION

A. Methodology

The proposed PulmoLens AI system follows a structured methodology that integrates web technologies with deep learning techniques to enable automated chest X-ray disease analysis. The overall workflow begins with user interaction through a browser-based interface, where authenticated users upload chest X-ray images for analysis. These images are transmitted securely to a Flask-based backend using RESTful APIs. The backend acts as the central controller, managing image handling, model inference, explainability generation, and result delivery.

Before analysis, each uploaded image undergoes a standardized preprocessing pipeline that includes resizing, normalization, and channel conversion to ensure compatibility with the deep learning model. A pre-trained DenseNet121 convolutional neural network, fine-tuned on a curated medical dataset, is employed for disease classification. The model predicts the most probable disease class along with a confidence score, ensuring reliable diagnostic assistance. To enhance transparency and trust in predictions, the methodology incorporates Grad-CAM based explainability, which highlights the regions of the X-ray image that influence the model's decision. This attention-based visualization allows users and clinicians to interpret the AI output more effectively.

B. Implementation

The implementation of the PulmoLens AI system is carried out using a modular and scalable architecture. The frontend is developed using HTML, CSS, and JavaScript, JavaScript providing a responsive and user-friendly interface for image upload, language selection, and result visualization. The backend is implemented in Python using the Flask framework, which handles authentication, image processing, language management, and communication with the deep learning model. MySQL is used as the database layer to store user details, analysis history, and metadata related to uploaded images.

The deep learning component is implemented using PoTorch, where DenseNet121 serves as the core CNN model. The network is trained and validated on categorized chest X-ray datasets containing Normal, Pneumonia, COVID-19, and Tuberculosis images. During inference, the trained model weights are loaded to ensure consistent prediction performance. Grad-CAM is applied to the final convolutional layer of the network to generate heatmaps that visually indicate influential regions within the lungs. Additionally, a multilingual explanation engine is integrated, enabling disease explanations to be presented in the user-selected language. Finally, the system supports automated PDF report generation, combining predictions, confidence scores, and explanations into a downloadable medical report. This end-to-end implementation ensures accurate diagnosis, interpretability, and accessibility within a single unified platform.

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V. RESULTS AND DISCUSSIONS

The proposed PulmoLens AI system was evaluated using a curated chest X-ray dataset consisting of Normal, Pneumonia, COVID-19, and Tuberculosis images. The DenseNet121 based deep learning model demonstrated strong classification performance during both validation and real-time inference. High confidence scores were consistently observed for correctly classified images, particularly for Pneumonia and COVID-19 cases, indicating the model's ability to learn meaningful pathological patterns from chest radiographs. Normal X-ray samples exhibited minimal activation and lower confidence for abnormal classes, further validating the robustness of the trained model.

To enhance interpretability, Grad-CAM visualization was integrated into the inference pipeline. The generated heatmaps provided clear visual cues highlighting lung regions that contributed most to the model's predictions. In diseased cases, activation was concentrated around clinically relevant areas such as lung opacities and peripheral regions, whereas normal cases displayed diffuse or negligible activation. Although Grad-CAM does not perform pixel-level lesion segmentation, it attention-based visualization effectively improves transparency and clinician trust by explaining the decision-making process of the model.

The multilingual explanation module significantly improved system accessibility by dynamically translating disease explanations into user-selected languages. This feature ensures inclusivity for users from diverse linguistic background and supports better understanding of diagnostic outcomes. Additionally, the automated PDF report generation module successfully complied predictions, confidence levels, explanations, and timestamps into structured medical reports suitable for documentation and sharing.

VI. CONCLUSION

This project successfully demonstrates the design and implementation of PulmoLens AI, and intelligent web-based system for automated chest X-ray analysis using deep learning. By leveraging a DenseNet121 convolutional neural network, the system accurately classifies chest X-ray images into clinically relevant categories including Normal, Pneumonia, COVID-19, and Tuberculosis. The integration of Grad-CAM further enhances model transparency by visually highlighting regions of interest that influence diagnostic predictions, enabling better interpretability and trust in AI-assisted medical decisions.

In addition to accurate disease classification, PulmoLens AI emphasizes accessibility and usability through its multilingual support and automated medical report generation. The system allows users to receive explanations in their preferred language and download structured PDF diagnostic reports, making it suitable for deployment in diverse healthcare environments. The Flask-based architecture ensures seamless interaction between the frontend interface, backend services, and deep learning modules, resulting in a responsive and scalable application. Overall, PulmoLens AI learning modules, resulting in responsive and scalable application. Overall, PulmoLens AI demonstrates the practical potential of explainable artificial intelligence in medical imaging, offering an effective preliminary diagnostic support too that can assist health professionals while improving patient understanding and engagement.

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