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AI-Powered Detection: Deep Learning for Automated Tuberculosis Diagnosis from Chest X-Rays

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ABSTRACT

Tuberculosis (TB) is a highly contagious infection caused by Mycobacterium tuberculosis, primarily affecting the lungs but capable of spreading to other organs. It remains a major global health concern, especially in developing countries. Early detection is vital for effective treatment and prevention. According to the World Health Organization (WHO), TB ranked among the top 10 causes of death worldwide in 2023, with approximately 10.6 million reported cases. Notably, over 50% of global TB cases are concentrated in India, China, Indonesia, and the Philippines. Traditional TB detection methods such as chest X-rays, blood tests, and clinical diagnosis face challenges like delayed results, low sensitivity, human error, and limited access to resources. To address these issues, deep learning-based TB classification has emerged as a promising alternative. This approach uses chest X-ray (CXR) images and applies Convolutional Neural Networks (CNNs) to automatically extract features and enhance diagnostic accuracy, often leveraging transfer learning techniques. Deep learning models can rapidly and accurately classify X-ray images to detect TB, helping reduce diagnostic delays and minimize human error. This automated system supports healthcare professionals by easing their workload and ensuring faster diagnoses especially critical in high-burden, resource-limited settings with a shortage of expert radiologists. Integrating deep learning into TB detection can significantly improve healthcare efficiency, patient outcomes, and contribute to global TB eradication efforts.

Keywords: Tuberculosis (TB) Detection, Chest X-Ray (CXR) Classification, Automated Diagnosis, Computer-Aided Diagnosis.

1. INTRODUCTION

Tuberculosis (TB) is a contagious disease caused by the bacterium Mycobacterium tuberculosis, primarily affecting the lungs but capable of spreading to other organs such as the kidneys, spine, and brain. The disease is transmitted through airborne particles when an infected person coughs, sneezes, or speaks. Factors such as malnutrition, overcrowded living conditions, and limited access to healthcare contribute to the high prevalence of TB in India. In 2021, India witnessed a 19% increase in notified TB cases compared to the previous year, highlighting the ongoing challenge the country faces in controlling the disease. The side effects of TB and its treatment can vary among individuals. Common side effects include nausea, fatigue, and potential liver complications. Some patients may experience skin rashes, itching, or gastrointestinal discomfort. In certain cases, more severe reactions such as blurred vision, dark urine, or jaundice may occur, indicating liver inflammation. It's crucial for patients undergoing TB treatment to be closely monitored by healthcare providers to manage and mitigate these side effects effectively. Understanding the classification of TB is essential for effective diagnosis and treatment. TB can be categorized based on the site of infection (pulmonary or extrapulmonary), the clinical manifestation (active or latent), and drug resistance patterns (drug-sensitive or drug-resistant). Accurate classification aids in determining the appropriate treatment regimen and helps in controlling the spread of the disease. Efforts to combat TB in India involve improving public health infrastructure, ensuring timely diagnosis, and providing effective treatment to reduce transmission and prevent the emergence of drug-resistant strains.

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2. LITERATURE SURVEY

R. Dinesh Jackson Samuel et al. [1] (2024) developed Tuberculosis (TB) detection using chest X-ray images was widely used for early screening in healthcare. The automatic detection of TB based on deep learning gained significant research attention. Convolutional neural networks (CNN) and pre-trained CNNs were the most commonly used models. Various datasets, data preprocessing, feature extraction, and classification techniques were explored. Performance evaluation metrics and visualization techniques were discussed to enhance model interpretability. Limitations in existing studies and future research directions for TB detection were also highlighted.

A. Abdelaziz et al. [2] (2024) Tuberculosis (TB) was ranked as one of the leading causes of death from infectious diseases, causing significant health and economic impacts in developing countries. Traditional diagnostic approaches remained in use but were slow, relative, and dependent on visual observations and touch. Advanced machine learning showed promise in improving TB diagnosis, identifying drug resistance, and aiding disease management. Various models, including deep learning, hybrid approaches, and metabolomics, demonstrated high sensitivity, specificity, and accuracy. ML was also used to analyze the molecular structure of TB and identify drug targets for future therapies. Despite its potential, challenges related to data quality, model interpretation, and ethical concerns hindered further applications. More investment was encouraged to overcome these barriers and enhance global health efforts.

Y. Yang et al. [3] (2024) Researchers developed a deep learning (DL) training framework using TensorFlow 2 to standardize and modularize the process of predicting drug resistance in Mycobacterium tuberculosis (MTB). They systematically evaluated modules from three representative models—Convolutional Neural Network, Denoising Autoencoder, and Wide & Deep—to assemble a novel model with appropriate components. Addressing limitations of previous models that relied on known resistance-associated loci, they employed a de novo learning method based on whole-genome mutations. The customized multilayer perceptron model achieved competitive performance, with mean sensitivity and specificity of 0.90 and 0.87, respectively

M. A. A. Al-qaness et al.,[4] (2024) Over the past decade, the availability and diversity of chest X-ray (CXR) datasets have significantly increased, coinciding with notable advancements in deep learning techniques. These developments have led to a surge in applying deep learning to detect and classify lung diseases. Researchers conducted an extensive review of over 200 studies from 2018 to 2023, employing advanced machine learning methodologies to analyze CXR images. This review categorized the studies based on the methods used and the types of lung diseases addressed, providing an in-depth examination of current limitations and future directions in this evolving field.

I. Abubakar et al. [5] (2025) Over recent decades, regions heavily affected by Mycobacterium tuberculosis have experienced a significant rise in mortality rates. Traditional diagnostic methods for tuberculosis have remained challenging, especially in high-prevalence, resource-limited areas, due to the labour-intensive nature of processing numerous images. To address this, researchers have developed automatic segmentation and classification technologies utilizing lung computed tomography (CT) scans, expediting and enhancing TB diagnosis. Deep learning (DL) has emerged as a promising solution, automating the analysis of lung CT scans to improve the speed and accuracy of TB detection. These advancements underscore DL's potential to revolutionize TB diagnosis, particularly in resource-limited settings.

G. Tamura, et al. [6] (2024) Tuberculosis remains a global health threat, necessitating rapid, automated, and accurate diagnosis for effective control. The traditional Ziehl-Nelsen (ZN) stained smear

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microscopy method for identifying Mycobacterium tuberculosis (MTB) is labour-intensive and subjective, prompting the exploration of alternative approaches. Between 2017 and 2023, machine learning (ML) methods have emerged as promising tools for automating TB detection in ZN-stained images. A systematic literature review during this period examined the performance metrics and dataset characteristics of these ML applications, identifying advancements, establishing the state of the art, and highlighting areas for future research. The review concluded that ML methods have the potential to automate TB detection in ZN slides confidently, reliably, and cost-effectively, which is significant for health systems worldwide.

S. Stirenko et al. [7] (2024) Researchers have developed an automatic tuberculosis (TB) detection system utilizing advanced DL models to address the challenges of subjective assessments in chest X-ray (CXR) analysis. Recognizing that a significant portion of CXR images is dark and non-informative, which can confuse DL models, they employed sophisticated segmentation networks to extract the regions of interest from the images. These segmented images were then processed by various convolutional neural network (CNN) models. Among these, EfficientNetB3 achieved the highest performance, with an accuracy of 99.1% and a receiver operating characteristic of 99.9%.

S. A. Jose et al. [8] (2025) Tuberculosis (TB) remains a critical global health crisis, necessitating intensified efforts for effective control. In 2022, approximately 10.6 million individuals worldwide developed TB, with 1.3 million fatalities, underscoring the disease's severity. Researchers have employed predictive modeling techniques, utilizing various machine learning models, to forecast TB incidence. These models incorporate impactful visualizations for comprehensive data exploration, analysis, and comparison. By developing and evaluating different machine learning models, the optimal performing model can be customized to a user-defined function.

3. PROPOSED SYSTEM

The healthcare industry continuously seeks advancements in disease detection and classification to improve patient outcomes. With the rise of artificial intelligence and deep learning, medical diagnostics have become more efficient and accurate. This chapter presents the proposed system designed to analyze medical images, particularly chest X-rays (CXR), for detecting abnormalities such as tuberculosis (TB). The proposed approach leverages Deep Learning Convolutional Neural Networks (DLCNNs) to enhance diagnostic accuracy and efficiency, minimizing human intervention while ensuring precise classification. Tuberculosis remains a significant public health concern worldwide, requiring early and accurate diagnosis to prevent transmission and improve treatment outcomes. Traditional diagnostic methods, such as sputum tests and X-ray evaluations by radiologists, can be time-consuming and prone to human error. The proposed system addresses these limitations by automating the detection process using a deep learning framework that efficiently classifies lung conditions as normal or TB-affected. This automation reduces the burden on medical professionals while enabling rapid and consistent diagnoses.

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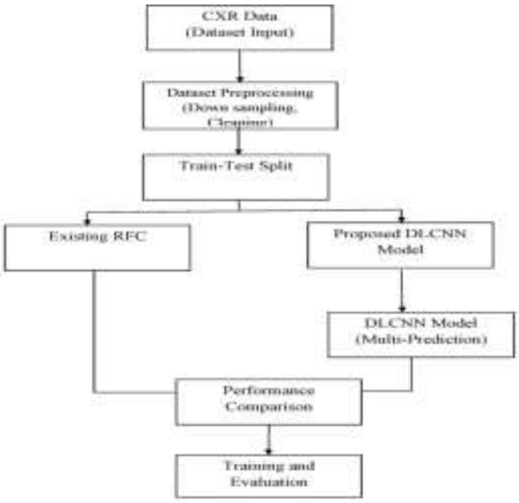

Fig. 1: System Architecture of Proposed System.

Deep Learning Convolutional Neural Networks (DLCNN) are widely used in medical image analysis due to their ability to extract complex patterns and features from images. In the proposed TB detection system, DLCNN is employed to classify chest X-ray (CXR) images into normal or TB-positive categories. The network consists of multiple layers, each serving a specific purpose in processing and learning patterns from the input images. The key layers include convolution with ReLU activation, max pooling, flattening, and fully connected layers

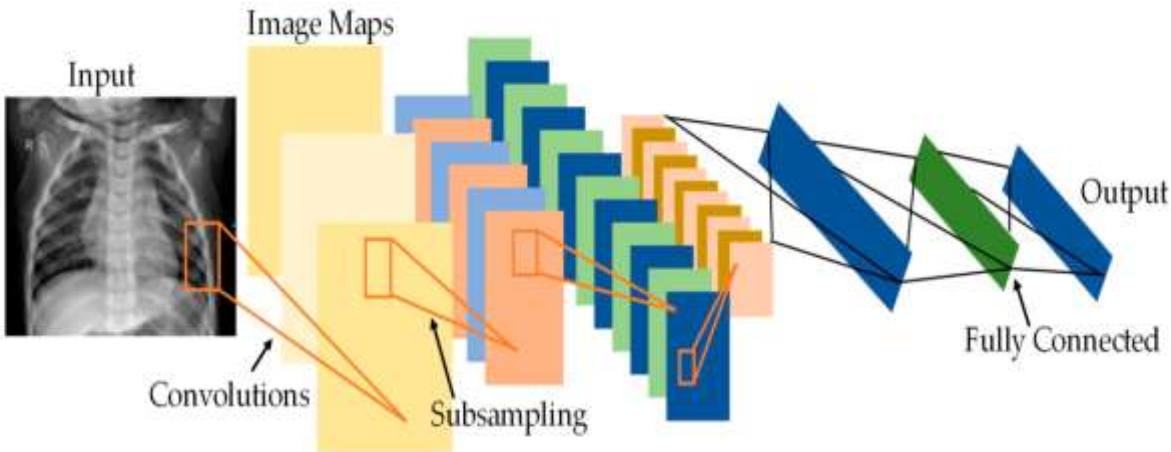

Fig. 2: CNN Convolution Operation example

The Input Layer is the first layer in a Convolutional Neural Network (CNN). It receives the raw image data and prepares it for further processing by the network. In a Convolutional Neural Network (CNN), the Input Layer serves as the entry point for data, typically receiving raw images represented as multi-dimensional arrays. For instance, a grayscale image might have dimensions (height, width, 1), while a color image would be (height, width, 3) to account for the RGB channels. This layer doesn't perform computations but structures the input data for subsequent processing by the network's layers. Proper preprocessing, such as normalization and resizing, is often applied to the input data to enhance the model's performance and stability. The Input Layer's primary function is to present the data in a format that allows the CNN to effectively learn and extract relevant features in the following layers.

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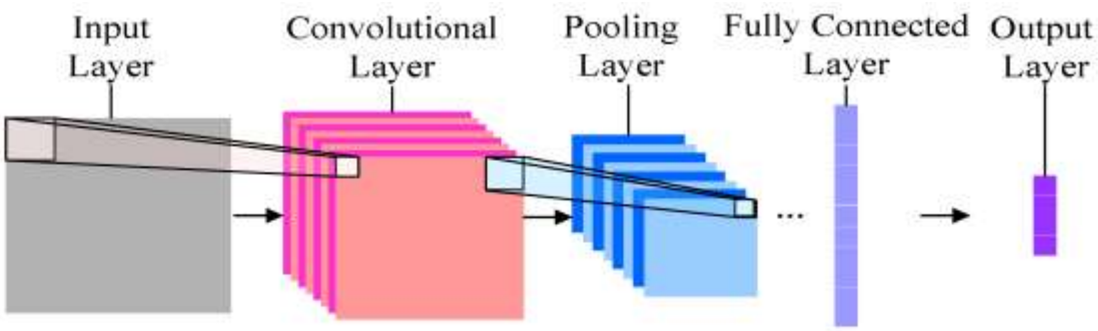

Fig. 3: CNN Layers

In neural networks, the output layer is the final layer that produces the model's predictions. Its configuration depends on the specific task:

Regression Tasks: The output layer typically has a single neuron with a linear activation function to predict continuous values.

Binary Classification: A single neuron with a sigmoid activation function outputs a probability between 0 and 1, indicating class membership.

Multi-Class Classification: Multiple neurons, each representing a class, use a softmax activation function to provide a probability distribution over all classes.

Selecting the appropriate activation function and loss function for the output layer is crucial for effective learning and accurate predictions.

4. RESULTS AND DISCUSSION

figure 4 displays a user interface featuring a registration form with a clean, structured layout. At the top, a mustard-yellow navigation bar provides links for "Home," "Register," and "Login," set against a gradient green header. The form includes fields for Name, Mobile, Email, Username, Password, and Confirm Password, along with radio buttons to select between "Admin" and "User," and a mustard-colored "Register" button for submission.

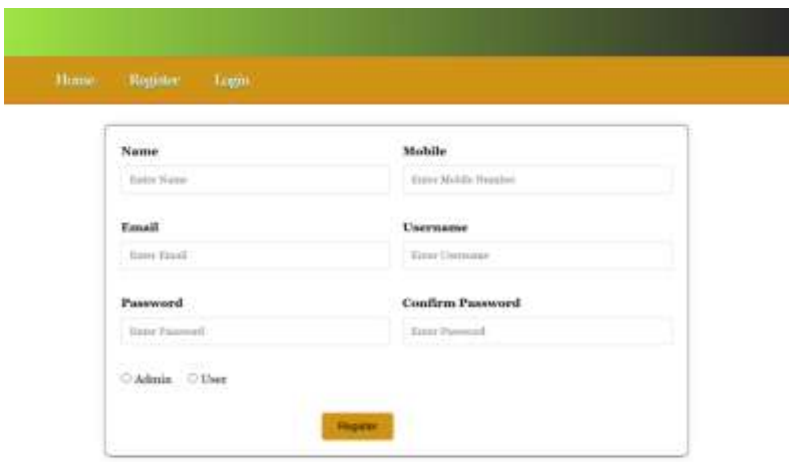

Fig. 4: Register Interface

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Fig. 5: Calculation Metrics (CNN Model Classifier)

This figure 5 displays a user interface presenting the calculation metrics for a CNN Model Classifier. At the top, a gradient green header contains the title, followed by a mustard-yellow navigation bar with links for "Decision Tree," "Random Forest," "CNN," and "Logout." The main section features a centered table under the heading "CALCULATION METRICS," displaying accuracy, precision, recall, and F-score values for the CNN classifier.

Fig. 6: Dataset Uploading

This image 6 presents a file upload interface for tuberculosis classification using a deep learning-based approach. The top section features a green gradient header displaying the system's title. Below it, a mustard-yellow navigation bar provides options for "Home," "Prediction," and "Logout." The main section contains a centered file upload form labeled "Test File," with a file selection button ("Choose File") and an adjacent text box displaying "No file chosen." Beneath the upload section, a mustard-yellow "Predict" button allows users to submit the selected file for analysis.

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Fig. 7: Output (Normal)

This image 7 shows a tuberculosis classification system displaying a prediction result. The interface retains its green gradient header with the title and a mustard-yellow navigation bar featuring "Home," "Prediction," and "Logout" options. In the main section, an uploaded chest X-ray image is displayed with a black label at the top stating "Predicted Output: Normal", indicating that the system has classified the X-ray as normal. The layout is clean, focusing on the prediction result.

Classifier	**Accuracy (%)**	**Precision (%)**	**Recall (%)**	**F1-Score (%)**
Decision Tree	94.05	89.81	86.96	88.30
Random Forest	95.00	93.45	86.90	89.77
CNN Model	98.61	93.45	86.90	89.77

Table 1: Performance comparison of various Algorithms

Table 1 below presents a comparative performance analysis among the classifiers tested, the Decision Tree Classifier achieved an accuracy of 94.05%, with a precision of 89.81%, recall of 86.96%, and an F1-score of 88.30%, showing strong but slightly lower performance compared to the other models. The Random Forest Classifier improved the overall accuracy to 95.00%, with a better precision of 93.45%, maintaining a similar recall (86.90%) and a slightly higher F1-score (89.77%) than the Decision Tree. The CNN Model, however, significantly outperformed both, achieving an impressive 98.61% accuracy, while maintaining the same precision (93.45%), recall (86.90%), and F1-score (89.77%) as the Random Forest. The CNN's superior accuracy suggests its ability to learn deep patterns in tuberculosis classification, making it the most effective model among the three.

5. CONCLUSION

In the study, a deep learning-based approach was employed for the classification of tuberculosis using a comprehensive image dataset. Multiple machine learning and deep learning models, including Decision Tree, Random Forest, and Convolutional Neural Networks (CNNs), were evaluated based on key performance metrics such as accuracy, precision, recall, and F1-score. The results indicate that while traditional classifiers like Decision Tree (94.05% accuracy) and Random Forest (95.00%

accuracy) performed well, the CNN model significantly outperformed them with an accuracy of 98.61%, demonstrating its superior capability in feature extraction and classification. The deep learning approach effectively captures intricate patterns in medical images, reducing misclassification and improving diagnostic accuracy. This highlights the potential of CNNs in automated tuberculosis detection, which can assist radiologists and healthcare professionals in early diagnosis, thereby enhancing patient outcomes. Future work could focus on further optimizing CNN architectures, increasing dataset diversity, and integrating explainability methods to improve model interpretability and robustness in real-world clinical applications.

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