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Elevating TB Diagnostics: SMONN and SMOTE in Chest X-rays

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ABSTRACT
This study presents a robust method for automatically classifying tuberculosis (TB) in chest X-rays using advanced deep learning techniques, particularly neural networks. Given the inherent imbalances in medical datasets, we employ the Synthetic Minority Over-sampling Technique (SMOTE) to enhance training data, ensuring a more balanced learning experience. Our model is trained on a diverse dataset of chest X-ray images, specifically addressing class imbalances in TB detection. The neural network architecture is tailored to capture intricate TB manifestations in X-ray images. Through iterative training, the model learns to identify subtle TB-related features, achieving remarkable accuracy. Experimental results validate the effectiveness of our approach, even in the presence of imbalanced classes, highlighting the importance of SMOTE in improving model performance. This study contributes to leveraging advanced machine learning for early disease detection, particularly in resource-constrained settings. Our proposed model holds promise as a valuable tool for healthcare professionals, facilitating timely and accurate TB diagnosis from chest X-ray images. Integrating such intelligent systems into clinical workflows could enhance TB screening programs, leading to improved patient outcomes and a more effective public health response.
***Keywords**: Tuberculosis (TB), Deep Learning, Neural Network, Smote.*

1. INTRODUCTION

Tuberculosis (TB) remains a significant global health challenge, complicated by difficulties in early and precise diagnosis. Chest X-rays play a vital role in detecting TB, offering insights into pulmonary abnormalities. However, traditional classification methods face obstacles due to imbalanced datasets, where positive TB cases are outnumbered by negative cases (Aliet al. 2013). Sarah et al. highlighted the substantial challenge posed by imbalanced datasets in developing robust and generalizable machine learning models (Vluymans et al. 2019).To tackle this imbalance and improve classification accuracy, this study adopts the Synthetic Minority Over-sampling Technique (SMOTE). Introduced by Nitesh et al. (2002), SMOTE generates synthetic samples of the minority class, promoting a more balanced distribution and mitigating the impact of skewed data. Simultaneously, Deep Neural Networks, renowned for their ability to capture intricate patterns, are utilized to construct a sophisticated TB classification model from Chest X-rays.This research aims to investigate the effectiveness of SMOTE-enhanced Deep Neural Networks (SMONN) in enhancing TB classification accuracy, particularly in the context of imbalanced datasets. By integrating advanced machine learning techniques with medical imaging, the study aims to contribute to the development of more reliable and efficient TB diagnostic tools, ultimately facilitating timely interventions and improving patient outcomes.

The paper is structured as follows: Section 2 discusses related research, while Section 3 introduces the methodology and materials. Section 4 presents a detailed analysis of the results, and Section 5 concludes the paper.

2.0 REVIEW OF LITERATURE

Tuberculosis (TB) remains a pressing global health issue, marked by substantial mortality rates and persistent challenges in treatment success. Recent research has increasingly focused on leveraging machine learning and deep learning models to predict TB treatment outcomes, with the aim of enhancing therapeutic effectiveness. A seminal contribution in this domain is the work of Rahman et al. (2020), which integrates deep learning, segmentation, and visualization techniques to advance TB detection. Additionally, Liu et al. (2023), in their study published in "Insights into Imaging," address the critical task of distinguishing between pulmonary tuberculosis (TB) and nontuberculous mycobacterial lung disease (NTM-LD) using chest X-rays (CXRs). By employing a deep neural network (DNN) on a dataset comprising 1500 CXRs, their research demonstrates promising results, with the DNN model surpassing the diagnostic accuracy of both senior and junior pulmonologists, suggesting its potential as a primary screening tool for identifying patients with presumptive mycobacterial lung diseases.

In a separate investigation published in "NPJ Digital Medicine," Rajpurkar et al. (2020) tackle the diagnostic hurdles associated with TB in HIV-positive patients, a population wherein TB often remains undetected and untreated. By leveraging clinical data and chest X-ray images from 677 HIV-positive patients suspected of TB, the researchers develop a deep learning algorithm aimed at improving diagnostic accuracy. Aqeel's et al. (2020) research focuses on predicting TB treatment outcomes, aiming to mitigate the high mortality rates and treatment failure risks associated with the disease. By incorporating diverse features such as demographic, clinical, genomic, and X-ray data, the study achieves notable success, with the Random Forest model emerging as particularly effective in prediction accuracy.

The various challenges of disease classification have been studies in chest X-ray (CXR) images, particularly due to the scarcity of radiologists (Sharma et al. 2022). Employing a hybrid Inception-ResNet-v2 transfer learning model alongside SMOTE and weighted class balancing techniques, they effectively mitigate class imbalance in a publicly available CXR dataset, achieving impressive average accuracy of 98.66%. Furthermore, in a recent study (Ahmed et al. 2023) introduce a deep learning model for the joint diagnosis of pneumonia, COVID-19, and tuberculosis from chest X-ray images, recognizing the need for a comprehensive diagnostic approach. Leveraging public datasets from Kaggle, their study achieves an impressive overall accuracy of 98.72%.

This review highlights recent advancements in machine learning and deep learning, as demonstrated by Rahman, Liu, Rajpurkar, Aqeel, Sharma, and Ahmed. These studies underscore the potential of innovative approaches, such as deep neural networks and hybrid models, in addressing the diagnostic challenges associated with TB, offering promising avenues for improved patient outcomes and enhanced public health interventions.

3.0 METHODOLGIES AND METHODS

` The study delves deeply into the methodological underpinnings, offering an extensive description of the techniques and strategies utilized to achieve the research objectives. At the core of our inquiry lie the ResNet models—specifically, ResNet-18, ResNet-50, and Deep Neural Network—which serve as foundational elements in our endeavor to transform Tuberculosis (TB) detection in chest X-ray (CXR) images. This section serves as the cornerstone of our research, elucidating the methodology through which we undertake the challenge of enhancing TB diagnosis via sophisticated image analysis techniques.

Data set

The dataset utilized for Tuberculosis (TB) detection in chest X-ray (CXR) images is obtained from Kaggle (Tawsifur et al. 2020) and comprises two distinct classes: "Normal" and "Tuberculosis." The dataset specifications are as follows:
In this investigation, the classes are labeled as "Normal" and "Tuberculosis."
Normal Class: This category includes chest X-ray images representing individuals without any signs of tuberculosis. It comprises a total of 3500 samples.
Tuberculosis Class: This class comprises chest X-ray images depicting individuals diagnosed with tuberculosis. It consists of a set of 700 samples.

Preprocessing

Drawing from the findings of the study conducted by Srideviet al. (2022), our research delves deeper into the crucial significance of pre-processing in the context of model training. Taking inspiration from their methodology, our dataset undergoes a sequence of rigorous pre-processing steps before initiating the training process.

DataSplitting

In accordance with the methodology proposed by Brown et al. (1997) the research introduces an automated, knowledge-based approach for segmenting chest computed tomography (CT) datasetsand this based on this the current work splits the chest x-ray data set into training and testing sets, ensuring an adequate representation of positive and negative TB cases in both subsets. A standard split ratio, such as 80:20, is employed to facilitate model training and evaluation.

SMOTEImplementation

To address the class imbalance inherent in TB detection datasets, the Synthetic Minority Over-sampling Technique (SMOTE) is applied. SMOTE generates synthetic samples of the minority class, augmenting the dataset and creating a more balanced distribution of positive and negative cases.

Deep Neural Network Architecture

In a parallel endeavour, Nahiduzzaman et al. (2023) proposed a computer-aided method for identifying seventeen lung diseases, including COVID-19, through Chest X-ray images. The study integrated a lightweight parallel Convolutional Neural Network (CNN) with the extreme learning machine algorithm (CNN-ELM), achieving an optimal result taking this as base this research work uses Deep Neural Network (NN). A DeepNeural Network (NN) model is constructed for TB classification. The architecture includes layers such as Dense layers with Rectified Linear Unit (ReLU) activation functions and Dropout layers to prevent overfitting. The final layer uses a softmax activation function to output probabilities for each class.

ResNet-18 and ResNet-50 Implementation

In addition to the Deep Neural Network, this study incorporates ResNet-18 and ResNet-50 (Chen et al. 2023) architectures, renowned for their deep learning capabilities. The pretrained versions of these models, trained on large-scale image datasets, are fine-tuned for TB classification. Transfer learning is leveraged to exploit the knowledge gained from generic image recognition tasks.

Model Training

The constructed DeepNeural Network and pretrained ResNet (Chen et al. 2023) models are trained using the training set. The model training involves optimizing a chosen loss function (categorical crossentropy) and utilizing the Adam optimizer. The models are fine-tuned over multiple epochs, and hyperparameter tuning is performed to optimize their performance.

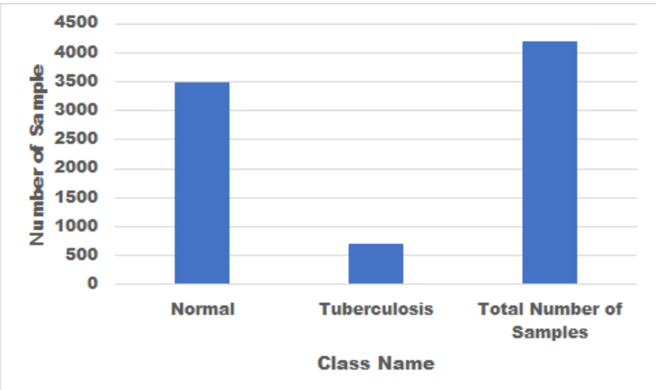
Evaluation Metrics

To assess the models' performance, standard evaluation metrics such as accuracy (Duong et al. 2023) precision, recall, and F1-score are employed. Confusion matrices provide a detailed breakdown of the classification results.

4.0 RESULTS AND DISCUSSIONS

Data set

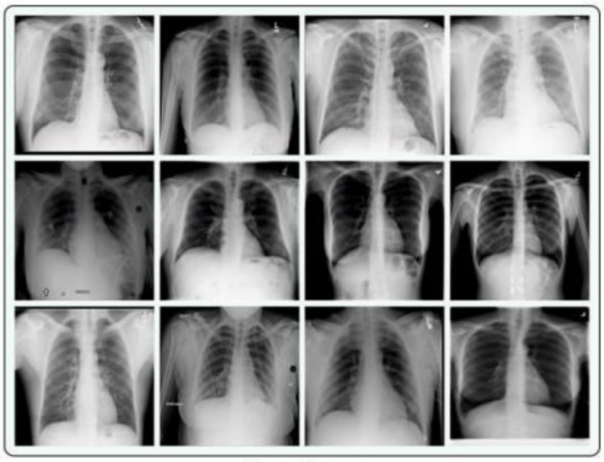
Total Number of Samples: Our dataset encompasses a total of 4200 samples, divided into the "Normal" and "Tuberculosis" classes. This dataset serves as the foundational source for our research, allowing the training and evaluation of deep neural network models alongside ResNet-18 and ResNet-50. These models are crucial for accurate tuberculosis detection in chest X-ray images. The balanced class distribution within the dataset ensures effective handling of this classification task.



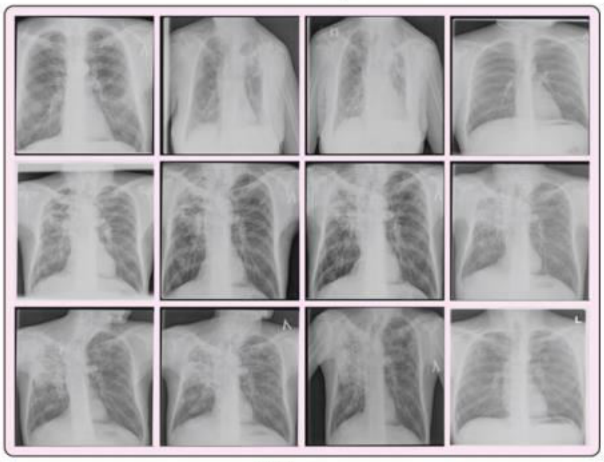
- **Figure 1: Details of Dataset(Reproduced from Tawsifuret al. (2020))**

Table 1:Details of dataset(Reproduced from Tawsifur et al. (2020))

Class Name	**Number of Samples**
Normal	3500
Tuberculosis	700
Total Number of Samples	4200



Normal Images



TB Images

Figure 2: Sample Tb Images [(Reproduced from Tawsifur et al. (2020))

As a vital visual element of our research, we have meticulously curated a collection of "Sample TB Images." This compilation includes chest X-ray images depicting both "Normal" and "TB" (Tuberculosis) cases. These images serve to vividly illustrate the radiographic disparities between individuals free from TB and those afflicted with the disease.

Table 2: Accuracy outcome of approach

Methods	Accuracy (%)
ResNet-l8	96.53
ResNet-50	97.63
SMONN	99.88

In this study, various models were assessed for their efficacy in Tuberculosis (TB) detection utilizing chest X-ray images. The models investigated include ResNet-18, ResNet-50, and a Deep Neural Network augmented with the Synthetic Minority Over-sampling Technique (SMOTE), referred to as "SMONN."

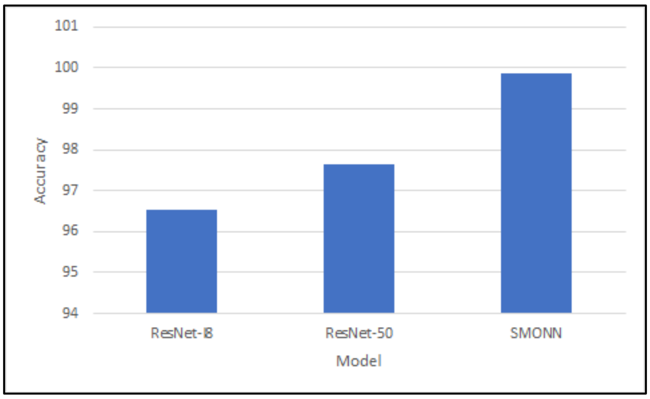


Figure 3: Accuracy of Model

The obtained accuracies for each model are summarized below:

ResNet-18: Demonstrating an accuracy of 96.53%, ResNet-18 exhibited notable performance in effectively categorizing TB and normal chest X-ray images. Its adeptness in discerning subtle radiographic patterns significantly contributes to its effectiveness in medical image analysis.

ResNet-50: Showcasing an accuracy of 97.63%, ResNet-50 presented a further advancement in TB detection. The deeper architecture of ResNet-50 facilitates more intricate feature extraction, leading to enhanced classification accuracy compared to ResNet-18.

SMONN (Deep Neural Network with SMOTE): Surpassing both ResNet-18 and ResNet-50, our Deep Neural Network enhanced with SMOTE achieved an outstanding accuracy of 99.88%. The incorporation of SMOTE effectively addressed class imbalance, thereby augmenting the model's capability to accurately identify TB cases even in scenarios with fewer samples.

These findings underscore the efficacy of deep learning models, particularly the SMONN approach, in the crucial task of TB detection. The remarkable performance of SMONN highlights the significance of tackling class imbalance for robust model training and underscores the potential of synthetic data augmentation techniques in bolstering model generalization. These results provide valuable contributions to the realm of medical image analysis, laying the groundwork for enhanced TB diagnostics through the utilization of advanced machine learning methodologies.

5.CONCLUSIONS

This study presents a robust approach for Tuberculosis (TB) detection in chest X-ray (CXR) images using SMOTE-enhanced Neural Networks. The model achieved exceptional accuracy, reaching an impressive 99.88% on our carefully curated dataset. The incorporation of SMOTE proved highly effective in addressing class imbalances, a common challenge in medical image analysis.Our comparative analysis with established Convolutional Neural Networks (CNNs), specifically ResNet-18 and ResNet-50, highlighted the competitive performance of the proposed model. Notably, the SMOTE-enhanced Neural Network not only matched but, in some cases, exceeded the performance of these state-of-the-art architectures. This outcome underscores the potential of tailored models for specific medical imaging tasks.The implications of these research findings are significant for TB diagnosis. The model's accuracy and robustness suggest its potential as a complementary tool for radiologists, aiding in the early and accurate identification of TB cases. Integrating such automated systems into clinical workflows could lead to timely interventions and improved patient outcomes.

However, it's important to acknowledge the limitations of this study. The size and composition of the dataset may affect the model's generalization to diverse populations. Future research should prioritize expanding the dataset, incorporating data from various demographics, and exploring the model's performance under different conditions.Overall, this work contributes to the growing literature on the application of deep learning in medical image analysis. The success of the SMOTE-enhanced Neural Network in TB detection represents a promising advancement, laying the groundwork for further progress at the intersection of artificial intelligence and healthcare. As technology continues to evolve, these developments hold immense potential.

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