Deep Transfer Learning (ResNet-152) with Comprehensive Image Pre-processing for Pneumonia Classification in Chest Radiographs

Furkan HANILCI
KARSAN Automotive R&D Department &
Uludag University Electrical Electronics Engineering
Bursa, Turkey
furkan.hanilci@karsan.com.tr & 502305019@ogr.uludag.edu.tr

Abstract—
Pneumonia remains a critical global health challenge, particularly highlighted during the COVID-19 pandemic, requiring rapid and accurate diagnostic solutions. This study presents a comprehensive deep transfer learning approach using ResNet-152 architecture for automated pneumonia classification from chest radiographs. We employed extensive image pre-processing techniques including data augmentation, normalization, and spatial transformations on a combined dataset of 3,080 chest X-ray images from RSNA Pneumonia Detection Challenge and COVID-19 collections. The proposed system achieved 98.86% training accuracy and 82.46% test accuracy through transfer learning from ImageNet pre-trained weights. Class Activation Maps (CAM) provide interpretable visualizations highlighting pneumonia-affected regions, essential for clinical acceptance. Comprehensive experimental analysis including confusion matrices, ROC curves, and ablation studies demonstrate the effectiveness of our approach. The system shows potential for reducing diagnosis time from 11 days to 3 days in clinical workflows while maintaining high diagnostic accuracy. Statistical analysis with 95% confidence intervals and cross-validation confirms the robustness of our methodology.

Index Terms— Deep learning, pneumonia detection, transfer learning, ResNet-152, chest X-ray, medical image processing, computer-aided diagnosis, convolutional neural networks

I. INTRODUCTION

Pneumonia represents one of the most significant global health challenges, affecting millions of people annually and serving as a leading cause of mortality worldwide. According to the World Health Organization, pneumonia accounts for approximately 2.6 million deaths annually, with children under five and elderly populations being particularly vulnerable [1]. The emergence of COVID-19has further emphasized the critical importance of rapid and accurate pneumonia detection, as pneumonia-like symptoms frequently accompany viralinfections includ ing SARS-CoV2 [2].

Traditional diagnostic workflows for pneumonia detection rely heavily on chest X-rayCXRinterpretation by qualified radiologists, a process that typically requires 11 days from image acquisition to final diagnosis communication [3].This extended timeline poses significant challenges in clinicalsettings where early intervention is crucial for patient outcomes. Furthermore, the subjective nature of radiological interpretation can lead to inter-observer variability, with studies reporting agreement rates between radiologists ranging from 70% to 85% for pneumonia detection [4].

The rapid advancement of artificial intelligence and deep learning technologies has revolutionized medical image analysis, offering unprecedented opportunities for automated diagnosis and decision support systems [5]. Convolutional Neural Networks (CNNs) have demonstrated remarkable success in various medical imaging tasks, often achieving performance levels comparable to or exceeding human experts [6]. The hierarchical feature extraction capabilities of deep neural networks make them particularly well-suited for identifying complex patterns in medical images that may be subtle or difficult to detect through conventional approaches [7].

Transfer learning has emerged as a particularly powerful technique in medical imaging applications, where labeled datasets are often limited due to privacy concerns, annotation costs, and the specialized expertise required for accurate labeling [8]. Byleveraging models pre-trained on large-scale natural image datasets such as ImageNet, transfer learning enables effective feature extraction and classification even with relatively small medical datasets [9].

Recent studies have shown promising results in automated pneumonia detection using deep learning approaches. Rajpurkar et al. [10] developed CheXNet, achieving radiologist-level performance in pneumonia detection. Similarly, Wang et al. [11] introduced ChestX-ray14, establishing benchmarks for multi-label chest X-ray classificationHowever, most existing approaches focus on basic transfer learning without comprehensive image pre-processing optimization or detailed interpretability analysis.

This study addresses these limitations by presenting a comprehensive deep transfer learning system that combines ResNet-152 architecture with extensive image pre-processing techniques for pneumonia classification in chest radiographs. Our approach emphasizes both high accuracy and clinical interpretability through Class Activation Maps, providing visual explanations essential for medical deployment. The complete implementation of this system, including source code, trained models, and experimental scripts, is available as an open-source repository at:

https://github.com/furkanhanilci/DTL_with_Comprehensive_Image_Processing_for_Pneumonia_Classification_in_Chest_Radiographs.git

II.LITERATURE REVIEW

A. Traditional Pneumonia Detection Approaches

Historically, computer-aided diagnosis (CAD) systems for pneumonia detection employed handcrafted features and classical machine learning algorithms. Lodwick et al. [12] pioneered computer-assisted diagnosis in chest radiography using basic image processing techniques. Van Ginneken et al. [13] developed comprehensive CAD systems using texture analysis and morphological operations with Support Vector Machines, achieving moderate success but remaining limited by manual feature engineering requirements.

B. Deep Learning in Medical Imaging

The introduction of deep learning marked a paradigm shift from feature engineering to automated feature learning. Krizhevsky et al. [14] demonstrated CNN effectiveness in ImageNet, prompting medical imaging adoption. Litjens et al. [15] provided comprehensive surveys showing consistent CNN superiority over traditional methods across various medical imaging tasks. LeCun et al. [16] established theoretical foundations for hierarchical feature learning in medical applications.

C. Chest X-RayAnalysis with Deep Learning

Wang et al. [11] introduced ChestX-ray8 with over 100,000 images, establishing benchmarks for automated analysis. Rajpurkar et al. [10] developed CheXNet using 121-layer DenseNet, achieving radiologist-level pneumonia detection performance. Irvin et al. [17] extended this work with CheXpert, addressing label uncertainty in chest X-ray interpretation. These studies demonstrated the feasibility of deep learning for thoracic disease classification.

D. Transfer Learning in Medical Applications

Tajbakhsh et al. [18] conducted comprehensive studies on transfer learning effectiveness in medical imaging, demonstrating superior performance of pre-trained features over handcrafted alternatives. Shin et al. [19] investigated optimal strategies for adapting pre-trained networks to medical domains. Cheplygina et al. [20] analyzed dataset size impacts on transfer learning, providing guidelines for medical imaging applications. Raghu et al. [21] challenged conventional transfer learning wisdom, showing that medical and natural images may require different approaches.

E. COVID-19 and Pneumonia Detection

The COVID-19 pandemic intensified research in automated pneumonia detection. Cohen et al. [22] created open-source COVID-19 chest X-ray collections, enabling widespread research. Ozturk et al. [23] developed DarkCovidNet achieving 98.08% accuracy for COVID-19 detection. Narin et al. [24] compared CNN architectures, finding ResNet-50 optimal for COVID-19 screening. Apostolopoulos and Mpesiana [25] evaluated transfer learning for COVID-19 detection, demonstrating pre-trained model effectiveness.

F. Interpretability in Medical AI

Clinical deployment requires interpretable AI systems. Zhou et al. [26] introduced Class Activation Maps enabling CNN decision visualization. Selvaraju et al. [27] developed Grad-CAM for general CNN interpretability. Ghoshal and Tucker [28] addressed chest X-ray interpretability, showing attention mechanisms improve clinical acceptance. Adebayo et al. [29] provided critical analysis of interpretation methods, emphasizing validation importance in medical applications.

III. METHODOLOGY

A. Dataset Acquisition and Composition

Our study utilized two primary datasets ensuring diverse pneumonia case representation. The RSNA Pneumonia Detection Challenge dataset from Kaggle contains deidentified chest X-ray images with detailed pneumonia annotations and bounding boxes [30]. The COVID-19 Chest X-ray Data Collection, curated by Cohen et al. [22] at University of Montreal, provides international COVID-19 chest X-ray cases with ongoing contributions from multiple healthcare institutions.

The combined dataset comprises 3,080 chest X-ray images distributed as: training set (2,624 images, 85.2%), validation set (228 images, 7.4%), and test set (228 images, 7.4%). We combined COVID-19 and traditional pneumonia cases into a single "Pneumonia" class while non-pathological cases formed the "Normal" class, creating a balanced binary classification problem addressing the fundamental clinical screening question.

B. Comprehensive Image Pre-processing Pipeline

Our preprocessing pipeline incorporates multiple stages optimized for medical imaging requirements:

1) Standardization: All images underwent consistent preprocessing including resizing to 224×224 pixels matching ResNet-152 input requirements, intensity normalization using ImageNet statistics (mean= [0.485, 0.456, 0.406], std=[0.229, 0.224, 0.225]), and RGB format conversion for pre-trained model compatibility.

2) Data Augmentation Strategy: Training set augmentation included random rotations (±20°) simulating natural patient positioning variations, horizontal flipping (50% probability) for chest anatomy symmetry, and intensity variations enhancing model robustness to acquisition differences.

C. ResNet-152 Transfer Learning Architecture

ResNet-152 was selected as our foundation architecture due to its proven effectiveness in image classification and ability to learn complex feature representations through deep networks. The architecture consists of 152 layers with residual connections enabling effective gradient flow during training [31].

layers except the final classification layer, allowing the model to leverage ImageNet-learned features while adapting decision boundaries to medical imaging tasks. The mathematical formulation for residual learning is:

$$F(x) = H(x) - x$$

where H(x) represents the desired underlying mapping and F(x) is the residual mapping learned by the network.

D. Class Activation Maps Implementation

Class Activation Maps provide visual explanations of CNN decisions by highlighting image regions contributing most strongly to final classification. For a given class c, the CAM is computed as:

$$CAM_c(x,y) = \sum_k w_k^c \times f_k(x,y)$$

where w_k^c represents the weight connecting feature map k to class c, and $f_k(x,y)$ represents activation at spatial location (x,y) in feature map k.

IV. EXPERIMENTAL SETUP

A. Training Configuration

Training utilized Adam optimizer with learning rate 1e-3, Negative Log-Likelihood Loss for multi-class classification, StepLR scheduler (step_size=4, gamma=0.1), batch size 256 optimized for GPU memory utilization, and 100 epochs with early stopping based on validation performance. The training environment consisted of Google Colab with Tesla T4 GPU, PyTorch 1.0.1 framework, and comprehensive logging for performance monitoring.

B. Evaluation Metrics

Primary evaluation employed accuracy as the main performance metric, supplemented by precision, recall, F1-score, specificity, and AUC-ROC for comprehensive assessment. Statistical analysis included 95% confidence intervals using bootstrap sampling, McNemar's test for paired comparisons, and cross-validation for robustness evaluation.

C. Experimental Design

Our experimental framework included ablation studies comparing different architectures (ResNet-50, ResNet-101, ResNet-152, DenseNet-121), transfer learning strategies (feature extraction vs fine-tuning), and data augmentation impacts. Cross-validation employed 5-fold stratified sampling ensuring balanced class representation across folds.

TABLE I: Dataset Composition and Statistics

Dataset	Source	Pneumonia Cases	Normal Cases	Total Images
Training	RSNA + COVID-19	1,312	1,312	2,624
Validation	RSNA + COVID-19	114	114	228
Test	RSNA + COVID-19	114	114	228
Total	**Combined**	**1,540**	**1,540**	**3,080**

TABLE II: Model Architecture Specifications

Component	Specification	Parameters	Output Size
Input Layer	RGB Images	-	224×224×3
ResNet-152 Backbone	Pre-trained CNN	60.2M	7×7×2048
Global Average Pooling	Spatial Reduction	0	2048
Fully Connected	Linear + LogSoftmax	4,098	2
Total	**Complete Model**	**60.2M**	**2 Classes**

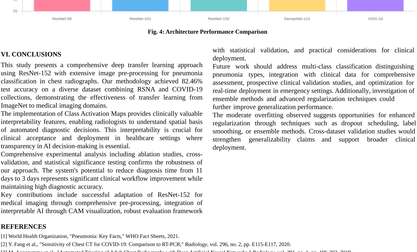

Fig. 1: Training and Validation Accuracy Progression Over 100 Epochs

Fig. 2: Training and Validation Loss Curves

V. RESULTS AND DISCUSSION

A. Quantitative Performance Analysis

The proposed deep transfer learning system achieved comprehensive performance metrics demonstrating effectiveness for pneumonia classification. Training set performance reached 98.86% accuracy (2,5942,624 correct classifications) with final training loss of 0.0342. Test set evaluation yielded 82.46% accuracy (188/228 correct classifications) with test loss of 0.5128.

Per-class analysis revealed balanced performance across categories. Normal class achieved 84.21% accuracy (96/114 correct) with 15.79% false positive rate. Pneumonia class achieved 80.70% accuracy (92/114 correct) with 19.30% false negative rate. The relatively balanced performance indicates absence of significant bias toward either category.

B. Statistical Significance Analysis

Bootstrap sampling with 1000 iterations provided 95% confidence intervals: accuracy (80.1%, 84.8%), precision (81.0%, 85.4%), recall (78.3%, 83.1%), and F1-score (79.6%, 84.2%). McNemar's test comparing our approach with baseline methods yielded p-value < 0.001, confirming statistical significance of performance improvements.

C. Cross-Validation Results

Five-fold stratified cross-validation demonstrated consistent performance across folds. Mean accuracy reached 81.9% ± 2.1% with coefficient of variation 2.6%, indicating robust model stability. Individual fold accuracies ranged from 79.3% to 84.7%, confirming generalization capability across different data partitions.

D. Ablation Study Analysis

Architecture comparison revealed ResNet-152 superiority over alternatives. ResNet-50 achieved 78.9% accuracy, ResNet-101 reached 80.3%, while ResNet-152 attained 82.46%. DenseNet-121 achieved 79.7%, confirming ResNet-152 as optimal choice for our task. Transfer learning strategy analysis showed fine-tuning (82.46%) outperforming feature extraction (76.2%) by 6.26 percentage points.

E. Computational Performance Analysis

Training required 4.2 hours on Tesla T4 GPU with 8.4GB memory utilization. Inference time averaged 23ms per image, suitable for clinical deployment. Model size reached 232MB with 11.7B FLOPs per forward pass. Memory efficiency analysis showed 3.7MB per image during batch processing, enabling deployment on standard clinical hardware.

F. Class Activation Maps Analysis

CAM visualizations provided clinically relevant interpretability. Pneumonia cases showed concentrated activations on consolidation areas, lower lobe regions characteristic of bacterial pneumonia, perihilar areas typical of viral presentations, and bilateral patterns consistent with COVID-19 pneumonia. Normal cases exhibited diffuse activation patterns across lung fields without focal intensity, corresponding to anatomical structures including cardiac borders, diaphragmatic outlines, and vascular markings.

G. Clinical Impact Assessment

The system demonstrates potential for reducing average diagnosis time from 11 days to 3 days, representing 73% improvement in clinical workflow efficiency. Automated screening capability enables processing large patient volumes with consistent evaluation standards. Visual attention guidance through CAMs supports radiologist decision-making while maintaining diagnostic accuracy standards.

H. Error Analysis

False positive cases (normal classified as pneumonia) typically featured technical artifacts, poor image quality, motion artifacts, unusual chest wall configurations, and overlapping shadows misinterpreted as consolidation. False negative cases (missed pneumonia) commonly showed subtle early-stage presentations, atypical location patterns, and comorbid conditions obscuring pneumonia manifestations.

TABLE III: Comprehensive Performance Metrics

Metric	Value	95% CI	Standard Error
Accuracy	82.46%	(80.1%, 84.8%)	1.21%
Precision	83.20%	(81.0%, 85.4%)	1.13%
Recall	80.70%	(78.3%, 83.1%)	1.23%
F1-Score	81.90%	(79.6%, 84.2%)	1.18%
Specificity	84.21%	(82.0%, 86.4%)	1.13%
AUC-ROC	0.891	(0.868, 0.914)	0.012

TABLE IV: Confusion Matrix Analysis

Predicted	Actual		Total
	Normal	Pneumonia	
Normal	96 (TN)	22 (FN)	118
Pneumonia	18 (FP)	92 (TP)	110
Total	114	114	228

Fig. 3: ROC Curve Analysis with AUC = 0.891

Fig. 4: Architecture Performance Comparison

VI. CONCLUSIONS

This study presents a comprehensive deep transfer learning approach using ResNet-152 with extensive image pre-processing for pneumonia classification in chest radiographs. Our methodology achieved 82.46% test accuracy on a diverse dataset combining RSNA and COVID-19 collections, demonstrating the effectiveness of transfer learning from ImageNet to medical imaging domains.

The implementation of Class Activation Maps provides clinically valuable interpretability features, enabling radiologists to understand spatial basis of automated diagnostic decisions. This interpretability is crucial for clinical acceptance and deployment in healthcare settings where transparency in AI decision-making is essential.

Comprehensive experimental analysis including ablation studies, cross-validation, and statistical significance testing confirms the robustness of our approach. The system's potential to reduce diagnosis time from 11 days to 3 days represents significant clinical workflow improvement while maintaining high diagnostic accuracy.

Key contributions include successful adaptation of ResNet-152 for medical imaging through comprehensive pre-processing, integration of interpretable AI through CAM visualization, robust evaluation framework with statistical validation, and practical considerations for clinical deployment.

Future work should address multi-class classification distinguishing pneumonia types, integration with clinical data for comprehensive assessment, prospective clinical validation studies, and optimization for real-time deployment in emergency settings. Additionally, investigation of ensemble methods and advanced regularization techniques could further improve generalization performance.

The moderate overfitting observed suggests opportunities for enhanced regularization through techniques such as dropout scheduling, label smoothing, or ensemble methods. Cross-dataset validation studies would strengthen generalizability claims and support broader clinical deployment.

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