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ViT-ILD: A Vision Transformer-based Neural Network for Detection of Interstitial Lung Disease from CT Images

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Abstract

Interstitial Lung Disease (ILD) is a lung illness characterized by inflammation and scarring. Identifying and categorizing ILD patterns using chest Computed Tomography (CT) images is crucial for diagnosis and treatment planning. Deep learning and computer vision advancements offer the potential for automating medical image examination, such as the transformer model, which identifies intricate dependencies and relationships in data. Chest CT scans provide valuable information for ILD pattern classification and diagnosis. The Vision Transformer (ViT) based Multi-Head Self Attention (MHSA) architecture detects local and global spatial dependencies, focusing on relevant regions and considering contextual interactions. The ViT-based model architecture aims to categorize ILD patterns using MHSA mechanisms. The proposed ViT-ILD model improves the performance by modifying hyperparameters, attention heads, and hidden units. It also utilises techniques of residual connections, layer normalization, and positional encoding for improvement. The proposed method ViT-ILD has achieved comparable training, validation and test accuracy of 100%, 98%, and 82.75% respectively for the 4-class classification with a healthy lung, hypersensitivity pneumonitis, pulmonary fibrosis, and tuberculosis from the MedGift CT dataset. It is observed that the proposed ViT-ILD model has achieved test accuracy, recall, precision, and f1-score of 82.75%, 74.15%, 100%, and 82.35%.

Keywords: Deep Neural Network; Vision Transformer; Interstitial Lung Disease; Chest CT.

1. Introduction

Interstitial lung disease is known as ILD. It is known as diffuse parenchyma disease, which alters the alveolar walls. ILDs affect 81 out of every 10 million men and 67 out of every 10 million women [1]. ILDs have known causes and unidentified causes. ILD examples include connective tissue diseases, occupational illnesses brought on

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by drugs and radiation, and illnesses linked to smoking. Idiopathic pulmonary fibrosis, eosinophilic ILD, and vacuities are examples of unknown aetiology of ILD [2].

A thorough patient history, physical examination, pathology test, imaging, bronchoscope, and thoracoscope biopsy are used to diagnose ILDs [2]. Chest initial evaluation of the pattern and distribution of parenchyma distribution with associated characteristics are captured using radiographic images. In older and more ill patients, invasive diagnosis is uncomfortable and frequently avoided. According to medical research [2], 90 to 95 per cent of ILD patients have radiographic images that are aberrant. The clinical context and distinctive CT findings in many ILDs suffice to make a diagnosis. Domain specialists are required for the correct interpretation and categorization of images, particularly High-Resolution Computed Tomography (HRCT) images.

The reasons [2] for choosing CT: are superior to traditional X-ray images in terms of detail and imaging quality, costs are reasonable, availability is good, contemporary multi-slice scanners with high spatial resolution, and scan duration is exceptionally brief. The trachea, bronchi, alveoli, and blood arteries make up the lung. Each of them is filled with lots of air. This characteristic of the lungs helps explain why lung CT performs better than MRI. The slight variation in density between normal tissue and lung lesions can be seen on a lung CT scan.

There are two methods used to categorize medical images: instance classification and semantic classification. Because each pixel in semantic classification has a matching category, the process is also known as "pixel-level classification". Instance category is also necessary for instance-level categorization in addition to pixel-level information. This sort of categorization is uncommon in reports of computer-based image classification efforts since instance information in medical images is sometimes difficult to get.

According to a certain ailment, classification provides a doctor with a specialized perspective of a certain portion of an image. The doctor can focus on a specific area of the image if the categorized image is overlaid with the original image. This is highly significant since the majority of doctors want to categorize the condition and measure its course by looking at the image and comparing it to the information they get by carefully reviewing the patient's medical history. Due to image quality, isolating a disease frequently requires highly specialized radiologists which are sometimes not available.

With the use of deep learning techniques, digital image categorization work has recently performed remarkably well. The study aims to create a vision transformer-based [3-6] neural network to accurately categorize ILD patterns from chest CT scans. The research plan involves collecting a comprehensive MedGift dataset [7] of chest CT scans with interstitial lung disease (ILD) patterns, including diverse subtypes. Expert radiologists annotated and labelled the ILD patterns, forming the foundation for training and evaluating the vision transformer model. The model is tested on an independent testing set using unseen CT scans. Comparative analysis with radiologists' interpretations and automated predictions using a vision transformer-based model will evaluate the model's clinical efficacy and potential as an assisting tool in diagnosing ILD. The performance of the proposed vision transformer-based model can be improved by modifying hyperparameters, attention heads, and hidden units. The improvement also can be done by utilising techniques of residual connections, layer normalization, and positional encoding in the vision transformer-based neural network.

In the next section, the state-of-the-art literature has been summarized. Section 3, describes the proposed ViT-ILD architecture with their advantages, dataset description is given in section 4, experimental results and analysis are discussed in section 5, and finally, the conclusion is given in section 6.

2. Related Work

Deep-learning algorithms are crucial for assisting doctors in identifying ILD trends in HRCT sections. The distribution of weight among hidden layers was examined in the study by Van et al. [8]. The method used a fully connected neural network, and gradient descent was employed to carry out supervised training. Six ILD patterns were categorized by Anthimopoulos et al. [9] with a CNN that had five convolutional layers. Using annotated areas of interest (ROIs) that radiologists have provided, patch-based categorization is carried out. The actual procedure takes a lot of time and is not as ideal from a clinical standpoint. Radiologists will benefit more from pattern identification at the section level. A pre-trained AlexNet model was employed in the work by Gao et al. [10] for fine-tuning. The classification task was conducted on a whole lung region. The input images were resized to meet the architectural layout of AlexNet and to take advantage of colour images that were intentionally produced utilizing

various attenuation windows. ILD classification was carried out by Shin et al. [11]. The existence of viral pneumonia [12] and ILD patterns [13] in a chest HRCT slice was identified in the current investigation using deep neural networks and modified U-Net by S. Saha et al. [14].

3. Methods

3.1. Vision Transformer-based Neural Network

We have proposed a new and efficient vision transformer (ViT) [4] based neural network for pulmonary fibrosis, pneumonia, and tuberculosis detection from Chest CT. To motivate detection, CAD technology has been built. In this paper, one such method that relies on ViT is introduced to detect diseases from chest CT images. CNN is the most effective method for classifying images. However, if the datasets (pre-training) are sufficiently vast, ViT outperforms CNN. ViT is built on the concept of transformer.

3.1.1. Transformer

A transformer [3] is a neural network architecture used in natural language processing tasks like machine translation, language modelling, and teaching book-living stages. It consists of an encoder and decoder with multiple layers, each generating secret images from input orders. The encoder and decoder work together to create the final output. Transformers can be trained on large-scale knowledge units using unsupervised pre-training methods like BERT and GPT, achieving state-of-the-art results across various NLP comparison points.

3.1.2. Encoder-Decoder and Embedding

The transformer architecture is the foundation for the ViT model, designed for visual activities. It consists [4] of an embedding connection, a decoder, and an encoder. The encoder embeds input pictures into patches, allowing the model to represent spatial connections between patches. The decoder makes predictions based on the encoded information. The embedding connection links the encoder and decoder, facilitating information exchange and facilitating the transition from visual to predictive domains.

3.1.3. Vision Transformer and Attention

The ViT model efficiently uses attention processes for image categorization tasks, focusing on relevant areas of the input image and considering contextual links between patches. This attention mechanism [3] captures long-range dependencies and spatial interactions, generating precise predictions and analyzing pictures as sequences of tokens. ViT takes the role of conventional convolutional layers in computer vision models, extracting significant features and developing rich representations for picture classification tasks.

3.1.4. Multi-Head Self Attention

Multi-Head Self Attention (MHSA) [3] is a self-attention technique in vision transformers that captures intricate correlations between image patches. It projects input embeddings into query, key, and value matrices, with each head receiving individual attention. ViT's multi-head self-attention mechanism has achieved high performance on benchmarks like ImageNet. A multi-head self-attention layer is fed a sequence of patch embeddings with positional embeddings. The weighted sum of the patch embeddings is computed using each set of attention weights computed by this layer. A new series of patch embeddings is created by concatenating and linearly projecting the outputs of the attention heads. The architecture of the proposed model is shown in Figure 1.

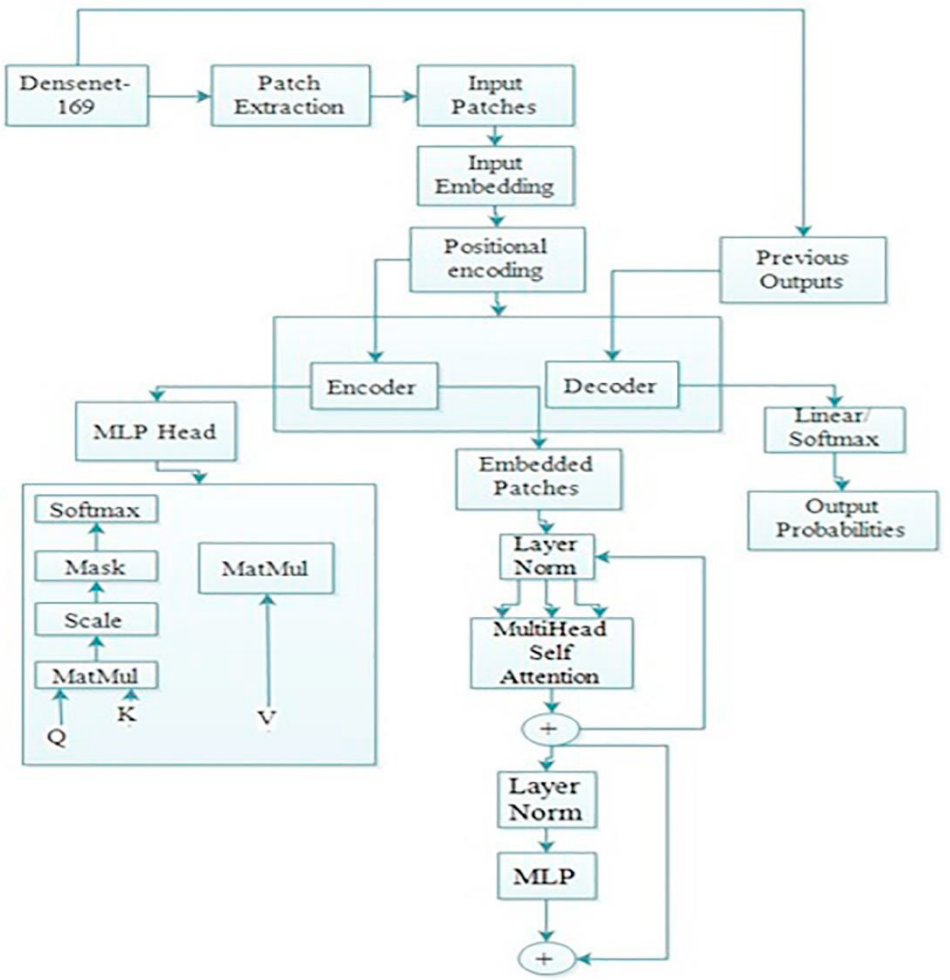


Fig. 1. Architecture of proposed model ViT-ILD

3.2. Dense Net Model

All layers of the densely connected network [15] are directly linked in an excellent feed-forward manner to allow maximum feature propagation and feature reuse between them as shown in Figure 2. It reduces the vanishing gradient problem and overfitting. DenseNet model with 169 layers uses pre-trained weights from ImageNet. Transfer learning is used on the top of the layer to identify lung disease.

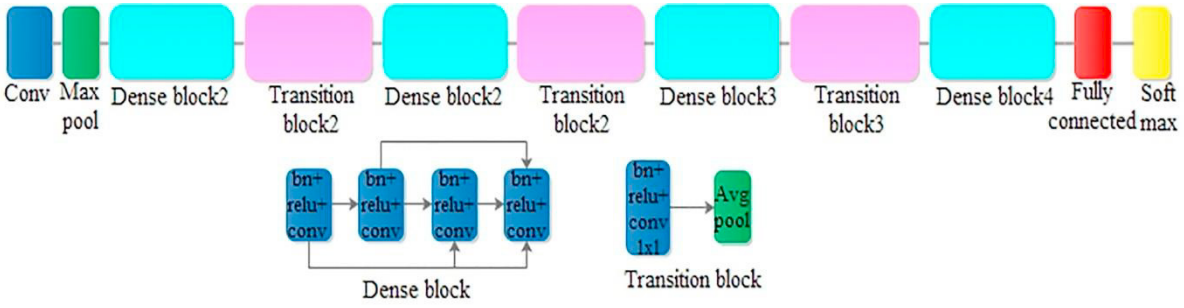


Fig. 2. Architecture of DenseNet169

3.3. Proposed Model

To enable image classification, the Vision Transformer (ViT) model's architecture employs a series of processes as shown in Figure 3. First, the DenseNet169 model is initialized with pre-trained ImageNet weights. The last convolutional layer of DenseNet produces the output tensor. Then, using a pre-determined patch size, a custom layer called patches is applied to extract patches from the DenseNet output. These patches are then sent to the patch-encoder layer, where positional encoding is inserted and enhanced to preserve spatial information.

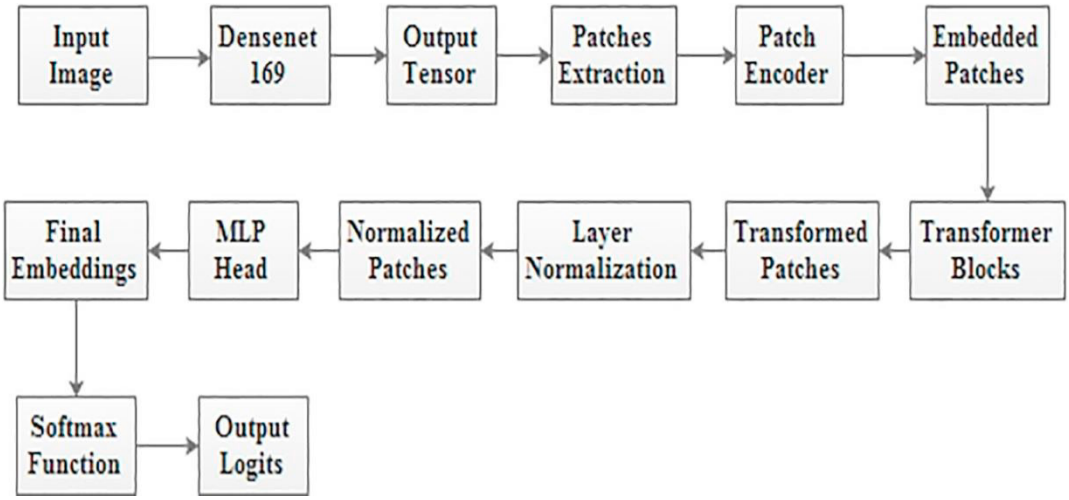


Fig. 3. Process flow of proposed model ViT-ILD

Following that, the embedded patches are input into various transformer blocks, each of which contains multi-head feed-forward and self-attention neural networks. After each transformer block, layer normalization is carried out to stabilize the training process and enhance performance. A key component of the ViT model's capacity to categorize images is the ability to capture complex relationships between individual image patches.

The output tensor is processed through the Multi-Layer Perception (MLP) head following the transformer blocks. Here, layer normalization is once more used, and then the tensor is flattened and dropout regularization is used to avoid overfitting. The final output logits are generated for classification using the flattened tensor after it has been passed through thick layers, with the number of output units equal to the total number of classes in the task.

The statement below can be used to model MLP head:
Output_Logits=Softmax(W2×Dropout(ReLU(W1×Layer_Normalization(Flatten_Transformer_Output_Tensor)))))

Layer normalization stabilizes the transformer output tensor, flattens it into a 1D vector, and represents the transformer output tensor with enriched image patch embeddings. Dropout regularization prevents overfitting, and ReLU introduces non-linearity to the MLP. The first dense layer in the MLP, or layer W1, represents the weight matrix and projects the flattened tensor to a middle representation. W2 stands for the second dense layer's weight matrix in the MLP, which converts the intermediate representation into the output logits. Softmax creates a probability distribution over the classes by applying the softmax function on the output logits.

In a summarized form, the proposed model architecture combines DenseNet169 as the base model and the vision transformer as the top model. The patches are taken from a pre-trained DenseNet169 model. These patches are then incorporated, combined with positional encoding, and processed via many transformer blocks with multi-head feed-forward networks, layer normalization being applied in between the blocks. After that, the output is run through the MLP head to provide the final classification logits for the input image patches, which include layer normalization, dropout, and dense layers.

4. Materials

In this study, we carried out the detection using the ILD MedGIFT dataset [7]. A total of 14 different categories of ILDs are available in the CT images of 103 patients in the ILD MedGift dataset. We have chosen the best CT images from each of the three ILDs- hypersensitivity pneumonitis, pulmonary fibrosis, and tuberculosis. These ILDs are compared to healthy lung CT. Figures 4 to 7 display the various CT image types.

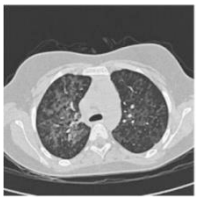


Fig. 4 [7] Hypersensitivity Pneumonitis

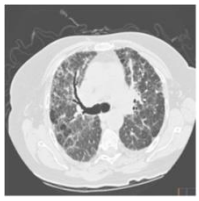


Fig. 5 [7] Pulmonary Fibrosis

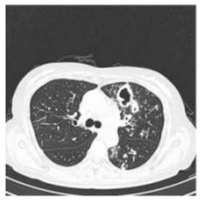


Fig. 6 [7] Tuberculosis

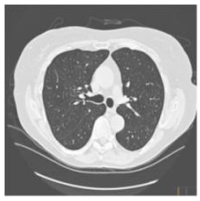


Fig. 7 [7] Healthy

We have used 235 HRCT images in total. These images are all extracted from the MedGift ILD dataset. Table 1 displays the numbers of HRCT images together with the respective category.

Table 1. Statistics of data split on MedGift ILD dataset [7]

CT of ILD	Training Set	Validation Set	Test Set	Total	
Hypersensitivity Pneumonitis	52	19	10	**81**	
Pulmonary Fibrosis	74	27	10	**111**	
Tuberculosis	12	3	3	**18**	
Healthy	13	5	7	**25**	
	151	**54**	**30**	**235**	**Total**

5. Results

The TensorFlow and Keras framework in Python is used to implement the proposed DNN model. The experiments use Google Colaboratory RAM and GPU.

5.1. Evaluation Metrics

The Confusion Matrix is generated for evaluating the proposed model. It is defined in Equation 1.

$$Confusion\ Matrix = \begin{matrix} \\ Actual \end{matrix} \begin{matrix} \text{Predicted} \\ \begin{pmatrix} TP & FN \\ FP & TN \end{pmatrix} \end{matrix} \quad (1)$$

Where TP: True Positive, FN: False Negative, FP: False Positive, TN: True Negative.

The model accuracy and loss are calculated by Equation 2 and Equation 3.

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (2)$$

$$Loss = \frac{FP+FN}{TP+TN+FP+FN} \quad (3)$$

5.2. Results of proposed ViT-ILD model classification task

We have a limited number of ILD images. We have applied a transfer learning approach by utilizing pre-trained DenseNet169 as the base model and ViT models as the top model. The proposed ViT-ILD model's training accuracy and validation accuracy graphs are shown in Figures 8 and 9 respectively. The equivalent loss graphs are shown in Figures 10 and 11. Nearly 100 epochs of the training and validation process are observed to have been executed. The model's performance is enhanced with following optimized parameters- batch size 4, image size 224×224, patch size 16×16, number of patches 196, learning rate 1e-2, weight decay 1e-3, projection dimension 128, hidden dimension 768, number of heads 6, number of transformer layers 8, size of transformer layer [256, 128], and size of MLP head [2048, 1024] is the size of dense layers of the final classifier. The performance results for the 4-class classification with a healthy lung, hypersensitivity pneumonitis, pulmonary fibrosis, and tuberculosis are shown in Tables 2 and 3 respectively.

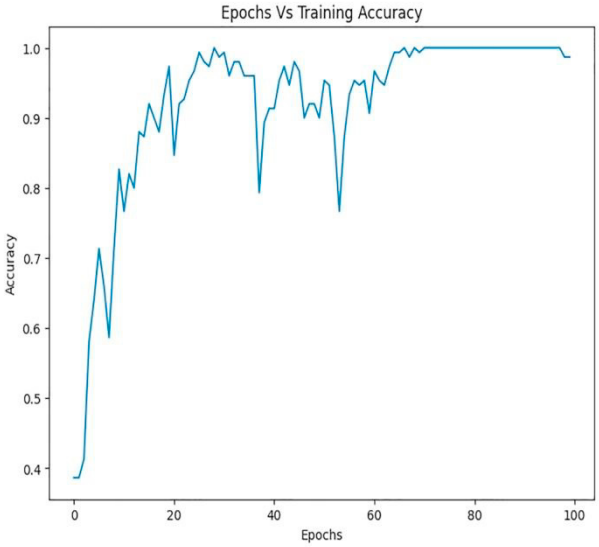


Fig. 8. Training accuracy of proposed ViT-ILD

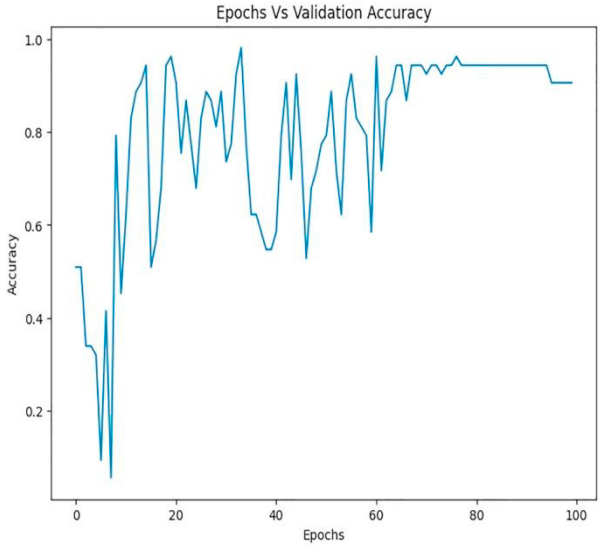


Fig. 9. Validation accuracy of proposed ViT-ILD

Table 2. Training results of ViT-ILD

Epoch	Accuracy	Loss
Epoch-1	0.38	12.38
Epoch-10	0.82	0.67
Epoch-20	0.97	0.07
Epoch-30	0.98	0.04
Epoch-40	0.91	0.30
Epoch-50	0.90	0.74
Epoch-60	0.90	0.43
Epoch-70	0.99	0.02
Epoch-80	1.0	0
Epoch-90	1.0	0
Epoch-100	0.98	0.06

Table 3. Validation results of ViT-ILD

Epoch	Accuracy	Loss
Epoch-1	0.50	9.27
Epoch-10	0.45	1.13
Epoch-20	0.96	0.18
Epoch-34	0.98	0.12
Epoch-40	0.54	3.52
Epoch-50	0.77	3.71
Epoch-60	0.58	12.35
Epoch-70	0.94	0.53
Epoch-80	0.94	0.45
Epoch-90	0.94	0.42
Epoch-100	0.90	0.62

It is observed that the training, validation and test accuracy become 100%, 98% and 82.75% for the proposed ViT-ILD. We have compared the test results of the proposed model with state-of-the-art models as given in Tables 4, 5, and 6. The proposed model is analogous to 4-class classification with ILD.

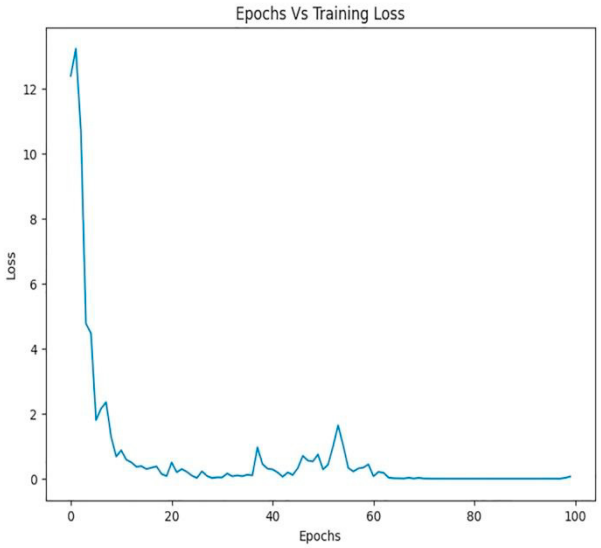


Fig. 10. Training loss of proposed ViT-ILD

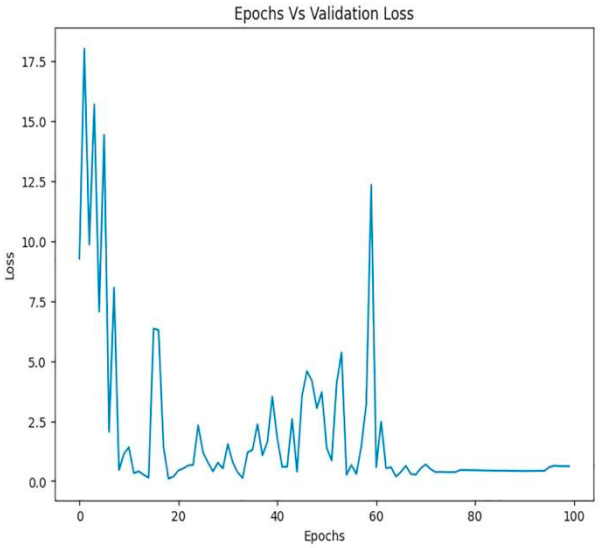


Fig. 11. Validation loss of proposed ViT-ILD

Table 4. Proposed model's test results are compared to the state-of-the-art on data [7]

Test Performances		**Confusion Matrices**				
Model	**ACC**	**Actual Class**	**Predict Class**			
			H	HP	PF	TB
ResNet50	62.06	H	4	0	2	0
		HP	0	4	6	0
		PF	0	0	10	0
		TB	0	3	0	0
Proposed ViT-ILD	**82.75**	H	**5**	1	0	0
		HP	0	**8**	2	0
		PF	0	0	**10**	0
		TB	0	2	0	**1**

H: Healthy, HP: Hypersensitivity Pneumonitis, PF: Pulmonary Fibrosis, TB: Tuberculosis

Table 5. Test classification report of the proposed ViT-ILD on ILD dataset [7]

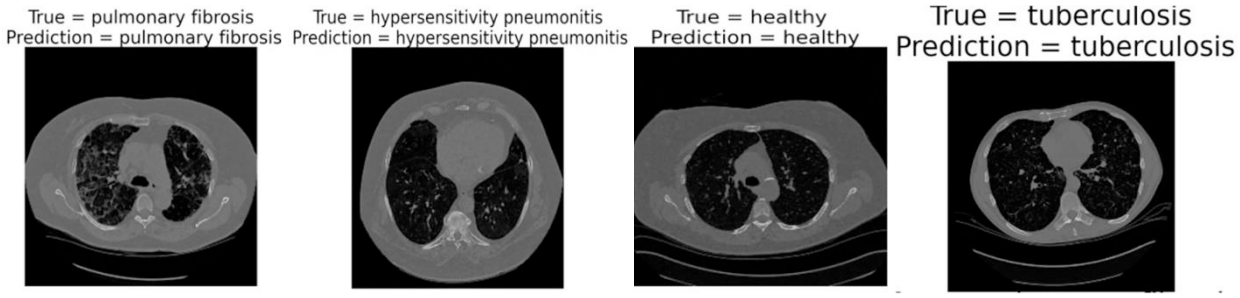
Class	**Accuracy**	**Recall**	**Precision**	**F1-score**
Healthy	92%	83.3%	100%	90.8%
Hypersensitivity Pneumonitis	90%	80%	100%	88.8%
Pulmonary Fibrosis	100%	100%	100%	100%
Tuberculosis	49%	33.3%	100%	49.6%
Average	**82.75%**	**74.15%**	**100%**	**82.35%**

It is observed that the proposed ViT-ILD model has achieved test accuracy, recall, precision, and f1score of 82.75%, 74.15%, 100%, and 82.35%.

Table 6. Comparison of test results to the state-of-the-art models

Authors	Models	Accuracy % (PulmonaryFibrosis)
S. Agarwala et al. [16]	GoogLeNet (MedGift ILD [7])	68
S. Soffer et al. [17]	CNN (MedGift ILD [7])	78-91
	Proposed ViT-ILD (MedGift ILD [7])	**100**

The output prediction of the proposed model is shown in Figure 12. The true value is the actual class label, and the proposed model automatically generates the predicted label.



(a) (b) (c) (d)

Fig. 12. (a-d): Predicted test outputs for the proposed ViT-ILD model

6. Conclusion

This paper has introduced the Vision Transformer (ViT) architecture to present a classification model for lung diseases. ViT's multi-head self-attention mechanism is used to enable the model to recognize complex connections and patterns in lung CT images, which helped to classify diseases correctly. The proposed model architecture combines DenseNet169 as the base model and the vision transformer as the top model. The patches are taken from a pre-trained DenseNet169 model. The patches are combined with positional encoding, and processed via many transformer blocks with multi-head feed-forward networks and layer normalization being applied in between the blocks. The output is run through the MLP head to provide the final classification for various lung diseases. The proposed method demonstrated the potential of ViT in medical image analysis by achieving impressive test accuracy, recall, precision, and f1score of 82.75%, 74.15%, 100%, and 82.35% for 4-class classification on the ILD MedGift CT dataset. Even if the results are encouraging, more analysis and adjustment are necessary to boost the model's functionality and clinical application. Overall, this study shows that the proposed ViT-ILD is effective in classifying lung diseases.

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