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Multi-Class Classification of Chest X-ray Images Using a Residual Capsule Network

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Abstract: This study introduces a novel deep learning network, ResCapsNet (Residual Capsule Network), for classifying patients as having COVID-19, tuberculosis (TB), or pneumonia using chest X-ray images. These networks address limitations of existing methods and achieve high accuracy, showcasing its potential as a valuable tool for automated diagnosis. Additionally, a user-friendly interface was developed for easy access by both healthcare professionals and the general public. Users can upload their chest X-rays (or those of a concerned individual) after signing up for the secure website and receive a predicted diagnosis.

This deep learning system analyzes and classifies the uploaded chest X-ray images using a hybrid deep learning model, namely, ResCapsNet. The uploaded image undergoes preprocessing (such as resizing, normalization, etc.) to ensure consistency. The preprocessed image is then fed into the hybrid model, which combines improved residual modules for feature extraction and capsule layers for final classification.

I. INTRODUCTION

The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has thrown the world into a state of flux. As of April 13, 2024, the reported global Case Fatality Rate (CFR) was around 1.4%. Even though COVID-19 cases have subsided in many parts of the world, the threat of new and potentially more dangerous variants is always imminent. They can be much more transmissible and deadlier.

The virus has the characteristic of long incubation period and causes several illnesses. According to the report of the World Health Organization (WHO), the main symptoms are cold, dry cough, fever, and so on. Moreover, there are 40%~50% asymptomatic patients, who are also infectious. Even if the patients visits a medical center, diagnosing COVID-19 without proper testing is challenging due to symptom overlap with diseases like tuberculosis (TB) or pneumonia. The infection is transmitted through the droplets of carriers, such as coughing and sneezing. Most importantly, there are currently no available drugs to prevent or control this virus. While RT-PCR tests have been most commonly used tool in diagnosing COVID-19, results can take hours or even days, which can further delay isolation and tracing the source of the spread.

Pneumonia is an infectious disease that fills alveoli with fluid and pus, causing the patient to experience shortness of breath and/or painful breathing. Additionally, pneumonia is the leading infectious cause of death in children under five years. Tuberculosis (TB) is the leading infectious disease worldwide, killing over 1.5 million people each year. It is caused by bacteria called Mycobacterium tuberculosis, and it affects the alveoli. Most deaths caused by TB are in low- and middle-income countries.

Therefore, Rapid and accurate diagnosis is very crucial to identifying COVID-19 patients and then the subsequent quarantine and isolation are best way to stop the transmission. In this study, we propose the use of a novel deep learning models, ResCapsNet, to classify and separate the patients with COVID-19 from other diseases like tuberculosis (TB), or pneumonia through the chest X-rays. The proposed networks address limitations of existing methods and achieve high accuracy, outperforming other approaches. We are also integrating the system with a user-friendly interface with easy access for not only healthcare professionals but also general public.

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II. LITERATURE SURVEY

Recently, deep learning-based CAD techniques have shown that they could identify numerous disorders on chest radio-graphs with accuracy comparable to expert radiologists. These approaches make use of unstructured data as input and attempt to extract more significant features from the input. With the extracted features, more accurate results are generated than classic diagnosis methods. Nowadays, CNN-based detection methods always classify and assess COVID-19-infected chest X-ray images or chest CT scans, which is treated as one of the most efficient ways. There are usually two categories; one is to take advantages of the medical imaging technology, such as the CT scans and CXRs. The other one utilizes the RT-PCR technology to detect COVID-19 disease. Compared with the methods with RT-PCR, chest X-ray and CT scan images are more efficient and convenient. Moreover, these images could be used to diagnose the location and shape of lung inflammation. Hence, Chest X-ray images and CT scans are being used primarily for COVID-19 disease detection. Many researches have given precise results using these medical images. H. Nasiri et al [1]proposed an efficient COVID-19 detection method employing DenseNet169 for feature extraction achieving a accuracy of 98.23% . Hamid Nasiri Naeem et al [2] proposed CovidDetNet, a ten-layer deep learning model with ReLu and Leaky ReLu activation functions, batch normalization, and cross- channel normalization. Achieving an accuracy of 98.40% Afshar et al. [3] proposed the COVID-19 detection capsulenet work withCXRs images, called COVID-CAPS network. They achieved 95.7% accu racy in the COVID-19 and non-COVID-19 classification Apostolopoulos et al. [4] made use of the CXRs image datasets to classify COVID-19 positive, common pneumonia and normal, in order to evaluate the performance of convolution neural network algorithm proposed in recent years for medical image classification. Their accuracy could reach 96.78% with the V2 Mobile-Net.

Song et al. [5] proposed the deep learning-based diagnosis network, named as DRE-Net. They categorized the CT scan samples into different classes and achieved 86% sensitivity and 94% specificity on the datasets Wang et al. [6] have used trans fer learning on a pre-trained convolutional neural network to categorize the input CXRs images and achieved 93.3%. Nigam et al. [7] designed the COVID-19 diagnostic system with the deep-learning framework, and achieved the classification of COVID-19 positive, pneumonia and nor mal and they obtained the 93.48% accuracy Hassantabar, et al.[8] Developed diagnosis and detection of infected tissue of COVID-19 patients based on lung x-ray image using convolutional neural network approaches . it can almost detect infected regions with high accuracy of 83.84% .

Altan, et al. [9] Made recognition of COVID-19 disease from X-ray images by hybrid model consisting of 2D curvelet transform, chaotic salp swarm algorithm and deep learning technique Tuncer et al. [10] proposed an automated Residual Exemplar Local Binary Pattern and iterative Relief based COVID-19 detection method using chest X-ray image, Chemo metrics and Intelligent Laboratory Systems end got an accuracy of 90.5%. Yoo, S.H, et al.[11] Designed deep Learning-Based Decision-Tree Classifier for COVID-19 Diagnosis from Chest X-ray Imaging., has accuracies of the first and second decision trees are 98 and 80%, respectively, whereas the average accuracy of the third decision tree is 95% .Hemdan, et al. [12]COVIDX Net: A Framework of Deep Learning Classifiers to Diagnose COVID- 19 in X-Ray Images with f1-scores of 0.89 and 0.91 for normal and COVID-19, respectively. Shibly, K.H et al.[13] COVID faster R–CNN: A novel framework to Diagnose Novel Coronavirus Disease (COVID-19) in X-Ray images, classification accuracy of 97.36%, 97.65% of sensitivity, and a precision of 99.28%. Ozturk,T., et al.[14] Automated detection of COVID-19 cases using deep neural networks with X-ray images, Computers in Biology and Medicines with an classification accuracy of 98.08% for binary classes and 87.02% for multi-class cases Narin, A., et al.[15] Automatic Detection of Coronavirus Disease (COVID-19) Using X-ray Images and Deep Convolutional Neural Networks with an 96.1% accuracy for Dataset-1 Das, N.N., et al.[16]Automated Deep Transfer Learning-Based Approach for Detection of COVID-19 Infectionin Chest X-rays. Lalmuanawma, et al.[17] Applications of Machine Learning and Artificial Intelligence for Covid-19 (SARS-CoV-2) pandemic.

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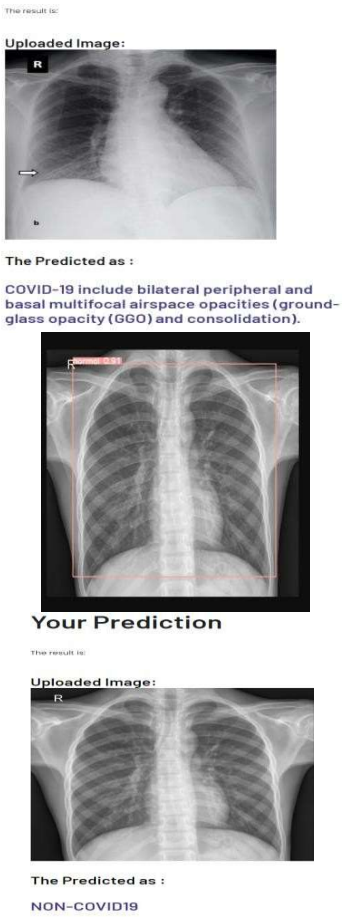

Fig: Predicted Outcome From The User Interface

III. PROPOSED SYSTEM

This deep learning system distinguishes COVID-19 cases from TB and pneumonia by analyzing the chest X-ray images using deep learning models. The uploaded images undergo preprocessing for consistency and improved analysis. Preprocessing is an important step in preparing images for deep learning analysis. It provides consistency and improves performance of the model. The common techniques used in preprocessing include resizing images to a standard size, adjusting pixel values for normalization and removing unwanted variations or artifacts from the image.

The preprocessed image is fed into a powerful deep learning model, ResCapsNet, for classification. This model has a very high accuracy in classification tasks. It is the integration of improved residual modules which are used for feature extraction and improved capsule networks which is specialized for classification. This system classifies the cases by COVID-19 or TB or pneumonia or No Findings and then displays the predicted outcome on the display.

A user-friendly web interface is developed to ensure accessibility for both healthcare professionals and the general public. After signing up for the secure website, users can select either classification or detection based on their needs. Then users have to upload their chest X-rays (or those of a concerned individual). Once an image is uploaded, the system will initiate deep learning analysis using ResCapsNet model for classification. Finally, the user will receive a predicted based on the model's output.

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IV. EXPERIMENTAL SETTINGS

The core of this project relies on Python, a versatile programming language known for its scientific computing and deep learning abilities. All the libraries we are using are built on top of Python. To determine the most suitable models for classification and detection tasks, we conducted extensive comparisons using Keras, a popular deep learning framework.

We conducted experiments to evaluate the performance of our proposed ResCapsNet model for multi-class classification of chest X-ray images. The system was trained to classify images into COVID-19, tuberculosis (TB), pneumonia, or No Findings categories.

For image preprocessing, we used OpenCV or scikit-image libraries for handling various image manipulation tasks which include resizing, normalization, and data augmentation techniques. Pandas imaging data management library is used for data loading, manipulation, and exploration.

Finally, to construct the user interface for the web application, Flask, web framework in Python, is used. Flask allows users to interact with the trained models by uploading chest X-ray images and receiving the predicted results. A simple and lightweight database, SQLite, is used within the web application for implementing user authentication functionalities i.e. Sign up and sign in.

Accuracy=(TP+TN)/(TP + TN + FN + FP)
Precision=(TP)/(TP+FP) Recall=(TP)/(TP+FN)
F1-score=(2*Precision*Recall)/(Precision+Recall)

Where,
True Positive (TP) represents the number of correct predictions that an instance is positive, whereas True Negative (TN) is the number of correct predictions that an instance is negative. False Positive (FP) represents the number of incorrect predictions that an instance is positive, whereas False Negative (FN) represents the number of incorrect predictions that an instance is negative.

V. RESULT AND CONCLUSION

To determine the most suitable models for classification task, we conducted extensive experiment comparing various deep learning models for classification from chest X-ray images.

In the extensive comparison conducted on deep learning models for classification task. This comparison involved training and testing a few diversely known models on our chosen dataset. The evaluation metrics focused on accuracy, precision, recall, and F1-score to provide a well-rounded assessment of each model's effectiveness as shown in the table. this comprehensive evaluation revealed that ResCapsNet model achieved the average accuracy of 98.47% among all other models.

CLASS	ACCURACY	PRECISION	RECALL	F1-SCORE
COVID-19	98.86	97.91	98.74	98.33
NO FINDINGS	97.57	98.43	99.17	98.97
PNEUMONIA	99.32	99.51	99.21	98.87
TB	98.13	97.81	98.24	97.98

Table1: Class-wise Performance

In conclusion, our project has prioritized the selection of high-performing models for classification within the user interface. As discussed earlier, the meticulous evaluation identified ResCapsNet as the optimal choice for classification, achieving an impressive accuracy of 98.47%. By integrating these best-in-class model, our user interface is equipped to deliver exceptional accuracy and reliability for our users.

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