AI Driven Cough Voice-Based COVID Detection Framework Using Spectrographic Imaging: An Improved Technology

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Abstract*— This paper develops an improved (more effective) and safer technology for detecting COVID-19 and thus contributes to the literature and the control of COVID-19. Coronavirus is a new infection that causes the coronavirus ailment called COVID-19. This disease was first found in bat at Wuhan, China, in December 2019. Starting from that time, it has spread rapidly throughout the globe. One of the main identifications of COVID-19 is that it can be handily distinguished by fever. Since this flare-up has begun, 'temperature screening utilizing infrared thermometers and RT-PCR has been utilized in advanced and developed countries to check the warmth of the body to identify the infected person. This is not a very effective way of detection, as it demands huge manpower and infrastructure to go and check one-by-one. Moreover, the close contact between the infected and the person checking can lead to the spread of coronavirus at a faster pace. This paper proposes a framework that can detect the coronavirus instantly and non-invasively from a human cough voice. The proposed framework is much safer as compared to conventional technologies used, as it reduces human interactions to a greater extent. It uses spectrographic images of the voice for COVID detection. This framework has been deployed in a web application to use them from any part of the world without exposing themselves to other infected people. This method encourages non-invasive mechanisms that will prevent from hurting sensitive areas, unlike conventional procedures.

Keywords*— *Spectograhic Imaging, Voice Analysis, Image Processing, COVID, Speech Recognition, ResNet-50

I. INTRODUCTION

Due to the overwhelming spread of the coronavirus, a lot of people got infected. In most healthcare centers, hospitals failed to admit patients due to a shortage of beds and infrastructure. Analysts from everywhere throughout the world are yet to deal with proficient identification techniques for this SARS-Cov-2 infection [1]. Experts presently utilize a few methodologies like Nucleic Corrosive Intensification Tests (NAATs), which have been highly effective in identifying the infection, and Serological Tests (ST) looking for antibodies in our bodies. The techniques that are used currently require physical closeness with the affected person, which increases the risk for both the staff and the patients. This requires immediate attention and prompt utilization of critical measures.

In this context, we aim to build a framework that detects the presence of COVID-19, using probabilistic measures based on audio features of the cough voice. Respiratory conditions, such as dry coughs, sore throat, excessively breathy voice, and dyspnoea plays a significant role in detecting the presence of COVID-19 [2][26]. Anyone can take the benefit of this framework remotely. Thus, it opens the way for remote diagnosis leading to minimal community spread. It also saves the hospitals and clinics from getting overburdened with calls and test appointments. [3] The primary motivation that was achieved for this project (use-case) is from the statements of experts who said COVID-19 primarily affects the vocal architecture and the tone [4]. According to EPFL, the cough associated with COVID-19 is a dry cough with a chirping intake of breath at the end. The significant contributions of this work are as follows.

a. Our approach analyzed the cough voice using their corresponding spectrographic images presented in [5]. By using spectrographic imaging, the model becomes more scalable, as the duration of the cough voice will not matter, as only a snapshot will be used to detect the presence of coronavirus.
b. Further, we have applied Convolution Neural Network on these spectrographic images to identify the patterns within those images and extract the detailed features that can help in the classification problem.
c. This approach takes the help of feature extraction from images, pattern recognition to produce binary class classification output, depicting the presence or absence of COVID-19.
d. We have also developed an application prototype for our proposed model to get an estimate of the performance.

The rest of the paper has been separated into nine sections. Section II, discussed the ongoing and past research studies relevant to our field of study All the basic technologies used in our overall research are highlighted in

Section III. The proposed approach is demonstrated in Section IV, followed by detailed implementation, results, and deployment in Section V. . Section VI discussed the structure of the dataset. Section VII and Section VIII discuss the result discussion of the overall project. Finally, in Section IX, we have discussed some of the challenges faced in this approach, followed by a conclusion in Section X.

II. RELATED WORKS, LIMITATIONS AND THE MOTIVATION FOR THIS WORK

Some of the European nations, as well as in France and Italy, have used voice analysis techniques for the detection of COVID-19. From Navi Mumbai Engineering College, some students recently worked on a voice analytical model. The conventional procedure used, RT-PCR. This method uses reverse transcription-polymerase chain reaction [9]. Normally it is known that RT-PCR takes 24 hours for its results to come. The new test - antigen test usually gives its result in 30 minutes. Earlier, a lot of studies have been done in the domain of Chest X-Ray. That was the first attempt to enter into the field of AI for the Non-Invasive methodology of detecting COVID 19. There are several papers, articles, news on this approach. Before this method existed, people used to undergo invasive saliva testing, which is risky and maybe sometimes harmful. Cornell University [10] has worked in this field and prepared an AI-based System that has an accuracy of 90% with a recall of 100%. Their research work was based on a similar context of reducing the invasive test, RT-PCR tests. Their research work has addressed the issue that everyone can't visit a dedicated place for the COVID test. To maintain the quarantine situation, they developed this novel system. Ozturk T, Yildirim EA, Talo M, Yildirim O, Baloglu UB, Rajendra Acharya in [11] have worked on a research project focused on a regular Chest X-Ray sequence. Based on the sequence, they trained a Novel Deep model which was used to predict whether the patient is Corona affected or not. Their basic objective was similar to previous work, but unlike the last one, they tried to consider a chest X-ray sequence to train their model. Kanafi AR, Ardakani AA, Khadem N, Acharya UR, Mohammadi in [12] researched different Convolution Neural Networks to detect the presence of COVID 19. Different popular convolution neural models were used like AlexNet, VGG-16, VGG-19, SqueezeNet, Xception, etc. Among all networks, the best performance was achieved by ResNet-101 and Xception. Kiran Purohit, Abhishek Kesarwani, Dakshina Ranjan Kisku, Mamata Dalui in [13] researched predicting SARS-Cov-2 with the help of Artificial Intelligence. Recently, two alternative approaches are mainly used for COVID-19 infection diagnosis - one is by analysis of X-Ray Images [14], [15], [16], [17] or CT scan [18], [19], [20],[25-27] images.

Existing works have several limitations and problems for detecting coronavirus: The current methods are not an effective way of detection due to their excessive demands for a huge workforce, infrastructure, etc. These technologies have the risks of the spread of coronavirus at a faster pace. This paper aims to develop a framework that can instantly detect coronavirus from a human cough voice that is much safer than conventional technologies used and reduces human interactions to a greater extent.

By achieving a better (more effective) and safer technology in this study, this paper contributes to the literature and the control of COVID-19.

III. BASIC TECHNOLOGY

A. Spectrographic Imaging

A spectrogram is a diagrammatic representation of the range of frequencies of the wave, which fluctuates with time. Spectrograms of sound are utilized to recognize expressed words in phonetics and to identify the difference in the sound of creatures. An optical spectrometer can produce a spectrogram, a bank of band-pass channels, by Fourier transform or by a wavelet change (in which case it is also called a scaleogram or scalogram). A spectrogram is usually portrayed in the form of a heat map, i.e., like an image with its different intensity due to the varying color or brightness. A typical arrangement is a diagram with two axes: one axis represents time, and the other axis represents frequency; a third measurement indicating the amplitude of a particular frequency at a specific time is represented by the intensity or shade at each point the image. Here the help of 'librosa.feature.melspectrogram' library has been taken to generate the spectrogram of our collected voice samples.

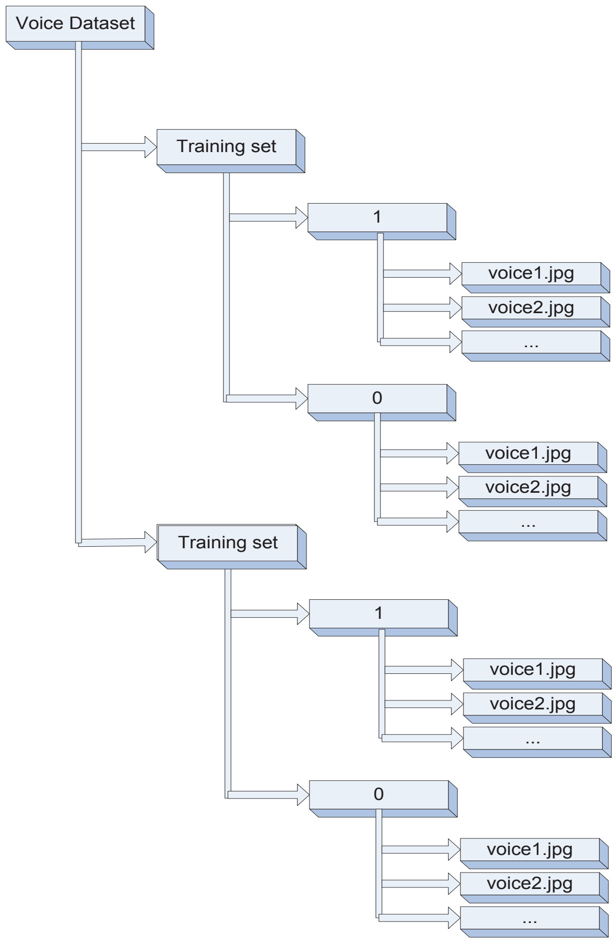

Fig. 1. Spectrographic image files directory arrangement

B. Image Processing

Images can be processed with the help of digital image processing techniques [21]. There exist two ways of interpretation, in which we can take the help of digital image processing techniques:

- horizon picking
- texture analysis of images

i. Horizon picking - Considering horizons as the sequential local extrema of reflection intensity is the simplest approach to horizon picking.

ii. Texture analysis of images - Texture analysis alludes to the portrayal of regions in an image by their texture content.

C. Speech Recognition

Speech recognition is an interdisciplinary subfield of software engineering and computational linguistics that creates procedures and innovations that empower the recognition and interpretation of spoken language into text by computers. It is also called automatic speech recognition (ASR), computer speech recognition, or speech to text (STT). It incorporates knowledge and research in the field of software engineering, linguistics, and other computer science fields.

IV. PROPOSED MODEL

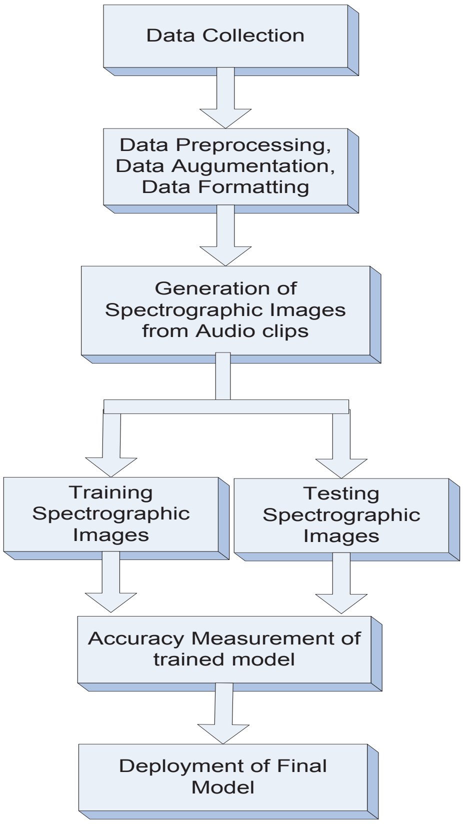

Fig. 2. Proposed Model

Audio data is a form of sequential data. The vibration of a human's vocal cords constantly produces a pressure wave, and by sampling them at discrete intervals, we can generate a sequence of real numbers. Recurrent neural networks can be a good choice to work within the case of audio data. But, as the cough voice data are extremely short, it would not be feasible to use a sequence learning model. Instead for our setting, we have used a Convolution Neural Network model over the spectrographic images of the voice to analyze the voice in the form of images. The proposed approach has been presented in Figure 2. The dataset gathered from Kaggle contained a large number of cough voice tests in .wav format. These cough voice tests are individually named based on their relating states. The cough voices taken from COVID-affected patients are named as '1', and those taken from healthy patients are named '0'. The voice tests have been grouped for non-affected individuals and affected individuals and stored in separate folders. Voice analysis is done with the assistance of 'librosa' library. This is one of the most popular libraries in python for representing voice information in the form of pictorial representation. With the help of the library, waveplot and spectrographic images of the voice samples have been generated. From these spectrographic images, we can get detailed information about the corresponding voice samples. To extract this information deep learning models have been used and trained. A convolution neural network model named ResNet-50 has been used. ResNet, short for Residual Network, is a trained DL network for the classification of images. ResNet 50 has a depth of 50 layers and is trained on many images from 1000 different categories from the ImageNet database. There are a total of 23 trainable parameters in the model, making it a deep architecture and improving its image classification performance. There are also other pre-trained models like AlexNet, GoogleNet or VGG-19, but ResNet-50 is very popular for its high generalization performance with very little error on classification. This model is trained on our dataset and has been prepared to classify whether it's a covid affected individual or a healthy individual.

V. DETAILS ABOUT DATASET

The dataset has been collected from the online repository Kaggle and arranged in a particular structure for convenient usage. The datasets consisted of voice samples in .wav format and a .csv file containing their current status, whether COVID affected or not. The dataset sample is displayed in Table I.

TABLE I. DESCRIPTION OF THE DATASET

Name of file	Type of file	Description
voice1.wav	.wav	contains the cough voice sample 1
data.csv	.csv	contains the corresponding health condition data for all the voice samples

The main directory 'Voice Dataset' is created and inside it, two sub-directories '1' and '0' are formed, where '1' represents the voice of COVID affected person and '0' indicates the voice of a healthy person. The voices were of a few minutes, and they are all stored in .wav format. These voice files were processed, and each of them was converted to their corresponding spectrographic images. The spectrographic images were stored in a specific directory format for convenient usage in later stages. The directory structure is presented in Figure 1.

VI. IMPLEMENTATION AND RESULTS

The first step was to learn how to manipulate audio data and build models that can classify sounds. A great dataset from Kaggle has been collected that consisted of a cough voice dataset of a massive number of people, each labeled as 0 and 1 based on whether the person whose cough voice it is, is covid affected or not. So the main problem was to classify a binary nodal state consisting of 'yes' or 'no'. After intensive research, it was concluded that only two methods are generally used which we can deal with this above use case. The cough voice dataset was analyzed thoroughly to extract the frequency, amplitude components from the voice. These components help to identify some common factors and patterns in the voice data, which further helps in the study. After the voice analysis, graphs for numerical component distribution were obtained. It has been displayed in Figure 3.

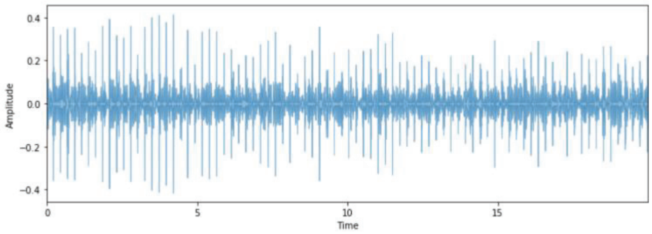

Fig. 3. Amplitude Envelope of the waveform.

We can see from the above images that there lies a very minimal characteristic difference. Thus, finding any particular pattern and observing the variance will be difficult, as our model will treat every voice factor similar [22]. Therefore, the classification can't be performed well. So, the first approach is to extract numerical features from the audio clips and understand the underlying sequence. As the interval of voice clips is short, it was decided to move on with the second approach, converting the voice to spectrographic images and then dealing with those images to classify using convolution neural networks (CNN).

Now when we are using the Convolution Neural Network, we must have some pictographic form of this voice data otherwise, it won't be possible for us to apply the Convolution Neural Network on the unstructured voice data. Further, we converted the voice data into its corresponding spectrographic imaging. Some sample spectrographic imaging is shown in Figure 4.

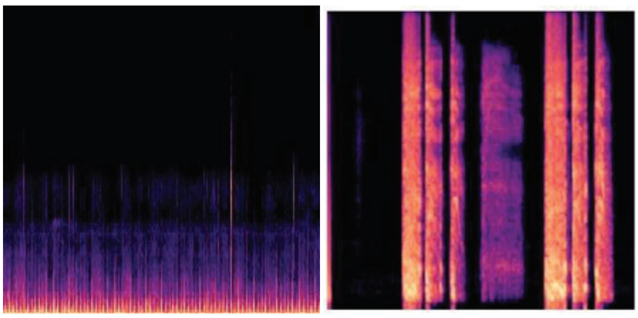

Fig. 4. Spectographic Images of the waveform.

These spectrographic images are then treated under Convolution Neural Network to train the model to classify these images based on covid affected or not. The Convolution Neural Network used in this case is ResNet-50. By using this model, we have achieved an accuracy of 93.5% over the cough dataset classification. In a more detailed way, a loop was created to access all the voice samples. The 'librosa' module function has been used within the loop to convert the individual voice samples to their corresponding spectrographic image. The spectrographic images were again split into training, validation, and test (60% training data, 20% validation data, and 20% test data). Keras, a framework that supports deep learning functionalities, have been used. Keras has some awesome modules to stack and preprocess images like. flow_from_dataframe, which has been used. This way, the training, validation, and testing data are stacked into generators and was processed into the model to train it. The ResNet-50 model was trained with the generated spectrographic data. An accuracy of 93.5% was achieved on the dataset. The training curve has been displayed in Figure 5, and the loss curve has been displayed in Figure 6.

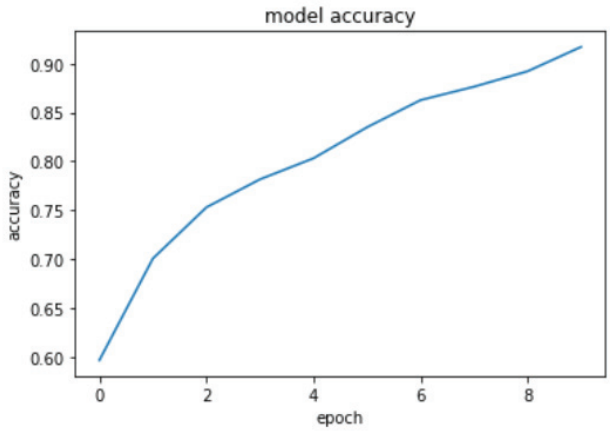

Fig. 5. Training Curve of the model.

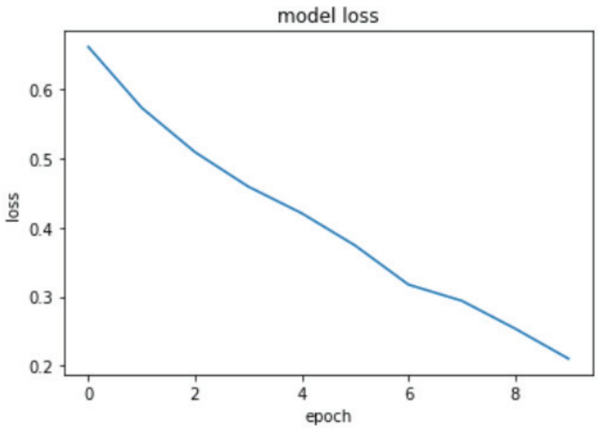

Fig. 6. Loss Curve of the model.

Along with the accuracy, it is also very important to concentrate on some other performance measures such as precision, recall, f1-score. There lies a slight difference between all these measures. Considering that we have a binary classification problem, so there is a total of four possibilities (i) where the original data is 'yes' and the prediction data is 'yes' (True positives, TP), (ii) where the original data is 'no' and the prediction data is 'no' (True negatives, TN), (iii) where the original data is 'yes', and the prediction data is 'no' (False negatives, FN), (iv) where the original data is 'no' and the prediction data is 'yes' (False positives, TN).

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FP}$$

Precision - Precision is the proportion of effectively anticipated positive perceptions to the absolute anticipated positive perceptions. We have got precision of 0.87 for '0' and 0.97 for '1'.

$$\text{Precision} = \frac{TP}{TP + FP}$$

Recall (Sensitivity) - Recall is the proportion of accurately anticipated positive perceptions to all real-class perceptions - yes. We have got recall of 0.99 for '0' and 0.70 for '1'.

$$\text{Recall} = \frac{TP}{TP + FN}$$

F1 score - F1 Score is the weighted mean of Precision and Recall [22-25]. Accordingly, this score takes in account both False positives and False negatives. Instinctively it isn't as straightforward as accuracy, yet F1 is normally more valuable than accuracy, particularly on the off chance that you have an uneven class distribution. Accuracy works better if False positives and False negatives have comparable cost. On the off chance that the cost of bogus positives and cost negatives are altogether different, it's smarter to take a look at both Precision and Recall. In our case, F1 score is 0.92 for '0' and 0.82 for '1'.

$$F1 - Score = 2 * \frac{\mathrm{Re}call * \mathrm{Pr}ecision}{\mathrm{Re}call + \mathrm{Pr}ecision}$$

The confusion matrix contains all the values of TP, TN, FP and FN in a single table. The confusion matrix is represented below in Table II.

TABLE II. CONFUSION MATRIX

	Predicted Yes	Predicted No
Actual Yes	1518	640
Actual No	46	3926

The precision, recall and f-score for our model are shown in Table III.

After the model has been trained, it has also been deployed on a web application with the help of the Flask framework. We have used Visual Studio Code IDE for building the web application. It is a very simple and easy-to-use application, but at the same time, it is very effective. Users can easily use this application to test the presence of coronavirus without any human intervention. The main focus of this application was to create a non-invasive detection infrastructure for covid detection that will not hurt the infected person and cause any health issue. In our application, there is an option to upload the voice file in .wav format. The pre-trained deep learning (Convolution Neural Network) model runs in the backend. After some epochs, it delivers the final output, the decision, on a separate page to display the predicted outcome. The corresponding voice's covid test is done, and the prediction is displayed whether it's the sound of a COVID-affected patient or not. Along with the predicted outcome, the spectrographic image that has been generated from the voice is also displayed for reference of the user and to make it more interactive. Thus, the user can very easily detect it easily with complete convenience and comfort. Figure 7 is the picture of the main page, where the voice file has to be uploaded in .wav format. After uploading the file, the ‘View Button’ for ‘Show result’ must be clicked to see the predicted result. Figure 8 and Figure 9 show the prediction page where the final prediction is displayed.

TABLE III. PRECISION, RECALL, F1-SCORE OF THE MODEL

Category	Precision	recall	f1-score	support
0	0.87	0.99	0.92	3972
1	0.97	0.7	0.82	2158
accuracy			0.89	6130
macro accuracy	0.92	0.85	0.87	6130
weighted accuracy	0.9	0.89	0.88	6130

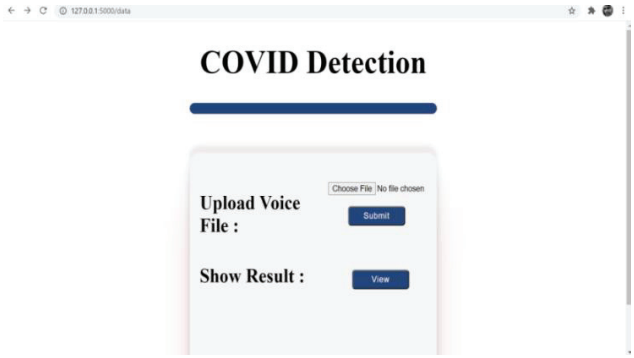

Fig. 7. Dashboard of the application

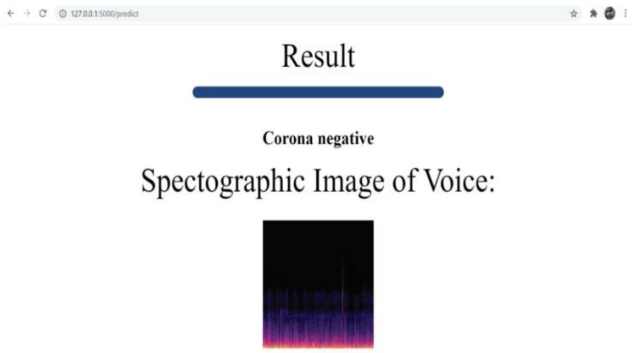

Fig. 8. Picture of prediction page where the outcome is negative.

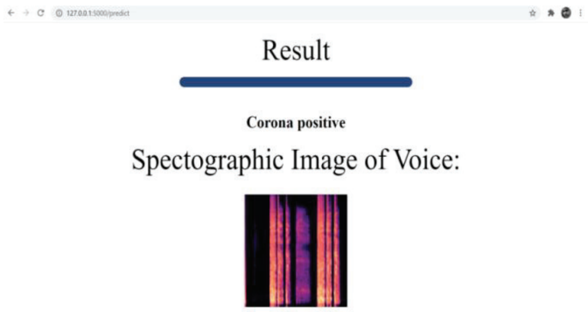

Fig. 9. Picture of prediction page where outcome is positive

VII. PERFORMANCE ANALYSIS AND VALIDATION

This section will present a detailed analysis of some of the image processing models in our application. It is a primary necessity to test with several models before finalizing the model. In our approach, we have tested three of the renowned convolution neural network models. The models tested are ResNet 152, Inception v3, ResNet 50. On testing, we came to the conclusion that ResNet 50 has proved to be the best models among the ones tested. We have done a detailed analysis of the performance measures on the training and testing set with all these models. The detailed report of the analysis is presented in Table 4. The variations were done with the base model, trainable layers, learning rate, and epochs for every model. The training and test accuracy in every case is calculated and tabulated.

TABLE IV.

Base Model	Initial weights	Trainable Layers	Learning Rate	Training Accuracy	Testing Accuracy
Resnet 152	Imagenet	Dense	0.001	90.11	91.11
Resnet 152	Imagenet	Dense	0.00001	86.57	87.57
Resnet 152	Imagenet	All	0.001	89.02	90.02
Resnet 152	Imagenet	All	0.00001	88.48	89.48
Resnet 152	Random	All	0.001	87.94	88.94
Resnet 152	Random	All	0.00001	87.4	88.4
Inception -v3	Imagenet	Dense	0.001	86.85	87.85
Inception -v3	Imagenet	Dense	0.00001	86.31	87.31
Inception -v3	Imagenet	All	0.001	85.77	86.77
Inception -v3	Imagenet	All	0.00001	85.23	86.23
Inception -v3	Random	All	0.001	92.59	92.52
Inception -v3	Random	All	0.00001	91.14	92.14
ResNet 50	Imagenet	Dense	0.001	93.5	93.5
ResNet 50	Imagenet	Dense	0.00001	93.2	93.2
ResNet 50	Imagenet	All	0.001	92.63	91.63
ResNet 50	Imagenet	All	0.00001	91.9	92.9
ResNet 50	Random	All	0.001	91.25	92.25
ResNet 50	Random	All	0.00001	91.02	92.02

From the graph and the table, we can easily see that ResNet 50 with ImageNet and dense as hyperparameters has performed the best among all the models used without any overfitting over the data. So, for our project, we have used it for training. It has given accuracy of 93.5%, which is good enough, keeping in mind that the data was highly imbalanced. To reduce the factor of imbalance, we have trained in the form of batches of images, where the number of covid positive patients and covid negative patients were kept similar. In the later stages of training, when the number of data increases, synthetic data can be generated from the existing data with the help of generative models such as Generative Adversarial Neural Network.

VIII. DISCUSSION OF RESULTS AND SOLUTIONS TO THE PROBLEM

One of the main challenges in this scenario is that the disease can't be detected early as the symptoms are not very specific. However, it can be identified and known after some days of an individual getting infected. Meanwhile, due to the high spreading nature of the virus, there are high chances of spreading from the victim to his/her surroundings. Moreover, there is no vaccine yet discovered, so it is very important to detect the virus sufficiently early to protect the victim and their surroundings. Based on the recent research and tests going around, it is known that the vocal tone and quality get affected at first due to the infection, which can be treated as vital information in detecting whether a person is infected. So a very widely used pipeline can be used that is voice detection using artificial intelligence. The difference in the voice quality is taken as the keynote in differentiating the affected person from others with the help of representational learning and feature learning from cough voice. AI can help in identifying the minute textures of voice. Here we have developed the prototype of an application that can be used to analyze a person's voice (cough voice) to detect COVID-19 symptoms. This will be useful as early detection can lead to the early quarantine of the person, thus ensuring the safety of that person and his surroundings. Also, treatment can be started based on the analysis report, and medical support can be taken early, which will be of great help. This application will also be easy to use. It has the AI incorporated within itself, using which people can regularly monitor and check their health conditions remotely (from their home). The proposed model is mainly aimed at initial screening and taking necessary actions of predicted COVID-19 individuals.

IX. RESEARCH CHALLENGES

One of the fundamental challenges we confronted in this research work is confirming that false positives are minimized. An excessive number of false positives (or false alerts) may produce extra tension in people and thus can lead to a chaotic situation, like people may rush to their nearest hospitals and overwhelm them. It implies the limited false negative cases. An excessive number of false negatives essentially means the application doesn't successfully identify COVID-19 indications. The goal is to have an application that identifies COVID-19 side effects with high accuracy while limiting false positives. AI algorithms can be trained and tuned to convey high exactness, although they cannot be 100% precise. Therefore, it is important to convey the error-performance metrics of the algorithms to users and ensure them with a certain confidence interval.

X. CONCLUSION AND FUTURE RESEARCH

This paper proposes a framework that can detect the coronavirus instantly from a human cough voice. The proposed framework is much safer compared to conventional technologies used, as it reduces human interactions to a greater extent. It uses spectrographic images of the voice for COVID detection.

The proposed approach can reveal a wider dimension for applications in areas such as medical check-ups. This novel method can be used in hospitals, homes, start-ups for easy non-invasive covid detection. More of its usage will gradually reduce human intervention and thus reduce the spread of coronavirus, thus saving a lot of people from getting affected.

Future research works may include usage of more advanced image processing models and more customized models. In extension to our proposed model wecan make the cough voice audio time dependent, and capture it for a specified time interval. These audio sequences captured can be used to extract voice frequency features using some numerical computations and advanced sequential learning models like LSTM, Transfer Learning models, etc can be implemented.

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