# COVID-19 DETECTION FROM CHEST X-RAY IMAGES USING DEEP LEARNING

## MOHAMMAD TAREK AZIZ

Rangamati Science and Technology University, Lecturer of Computer Science and Engineering at Chittagong Institute of Engineering and Technology, Chittagong, Bangladesh. E-Mail: tarekaziz4288@gmail.com

## JUEL SIKDER

Assistant Professor, Department of Computer Science and Engineering, Rangamati Science and Technology University, Rangamati, Bangladesh, E-Mail: juelsikder48@gmail.com

## TAOHIDUR RAHMAN

Rangamati Science and Technology University, Lecturer of Computer Science and Engineering at United College of Aviation, Science and Management, Dhaka, Bangladesh.
E-Mail: taohidurrahmanshomrat@gmail.com

## ARMANDO DACALCAP DEL MUNDO

Quality Assurance Officer, MIT/PhD-TM (CAR). E-Mail: armand02ph@yahoo.com

## S.M FAHIM FAISAL

Lecturer, Department of Mechatronics and Industrial Engineering at Chittagong University of Engineering and Technology (CUET), E-Mail: fahimfaisalmie@gmail.com

## NAYEEM UDDIN AHMED KHAN

Electrical and Electronics Engineering, University of Chittagong. E-Mail: nayeemuddina.khan@gmail.com

**Abstract**

At present, COVID-19 has become a severe threat to students, teachers, doctors, scientists, and governments all over the world. It is a single-stranded RNA virus with one of the enormous RNA genomes, and it is changing through mutation in every day. Sometimes this mutation results in a new variant. According to medical research of COVID-19 infected patients, these individuals are most commonly infected with a lung illness after coming into touch with the virus. So, find out COVID-19 from a chest X-ray image is an appropriate technique. But another issue arises when it shows that other diseases like viral pneumonia, and lung opacity also had common symptoms like as COVID-19 and these problems also can be detected from chest X-ray images. So, in this research, we proposed a deep learning approach based on modified VGG-16 for detecting COVID-19, viral pneumonia, lung-Opacity, and normal chest. We used the COVID-19 Radiography dataset to evaluate the performance of the proposed system. The accuracy of classification using the proposed method is 92.28%.

**Keywords:** COVID-19, Modified VGG-16, X-RAY, Viral Pneumonia, Lung-Opacity, Normal chest.

## 1. INTRODUCTION

At first, COVID-19 was seen in Wuhan, China in December 2019. The virus was highly widespread by March 2020. A different variant of the virus has gotten yet. The running virus "OMICRON ", Delta variants etc. infected patients are increasing day by day in the world.

Total 298,915,721 confirmed cases are COVID-19 positive 5,469,303 deaths 9,118,223,397 cases vaccine doses are complete in the world [1].

The cumulative numbers of confirmed cases of COVID-19 are being increasing day by day. Though, vaccine doses, it is difficult to control COVID-19 in the world. In 222 countries (total), the violence of COVID-19 is continued [2]. CORONA VIRUS is the running discussed virus in the world now. We will try to detect this virus in our research. The running virus has some symptoms discussed in some web-based sites. These symptoms are Runny nose, Headache, Fatigue, Sneezing, and Sore-throat [3] [4]. We aim to detect COVID or Normal reports from a given X-Ray image using deep learning models. In this system, we used a modified VGG-16 model that gives 92.28% accuracy in classification and model accuracy.

4 kinds of datasets are used in our research. These are COVID, Normal, Lung-Opacity, and Viral-Pneumonia images. A total of 21,165 X-Ray images are used. If we give an X-Ray image as an input in our proposed system, the machine can give the percentage of COVID or Normal result in the research. Our proposed methodology is useful for the medical diagnosis system. Some software is used in this research such as Anaconda, jupyter notebook, Google Colab, Pycharm, etc. Pre-processed datasets are used in the jupyter notebook for COVID detection. Firstly, data pre-processing is done in the jupyter notebook. The dataset named COVID-19 Radiograpgy database is collected from the Kaggle repository. It has four kinds of data [5]. Using Chest X-Ray images COVID-19 patients can find out. A total of 80% of X-Ray images were training and 20% for validation and testing. If we give an X-Ray image as input then the machine can give the percentage of COVID possibility and Normal result of that image based on its training. The prediction is more efficient and effective and our proposed model is more than 90% accurate. More than 21,000 datasets are used in this research. Total accuracy is also has more than 92%. This system can predict COVID positive percentage and normal percentage from an X-Ray image. VGG-16 is one kind of CNN architecture. It is used in large scale image recognition [6]. Besides, VGG-19, Bi-LSTM, CNN and SVM can also use for COVID-19 prediction [7]. Based on data training and validation we find a confusion matrix which is in our system. Dataset is trained after pre-processing. Pre-processed data are converted into gray-scale for training. The 2D dataset can use for training especially. A total of four kinds of the dataset are pre-processed and then trained. These are COVID, normal, lung opacity, and also pneumonia, lung opacity is considered a normal dataset. Based on datasets, frequency polygon also can show, which gives accurate results to us. Many research papers proposed their method to find out COVID is positive or negative in different ways. The majority percent paper of them used at most 3000 image datasets in their system and they used two classifications of images. But we used a total of 21,165 image datasets with four categories of image classification to find out the COVID possibility or not from the input image. This virus is a running issue in the world and scientists are trying to control it in many ways. The research is continuing in the whole world now.

In the result section, some laws are used to find out the precision, recall/sensitivity, and F1 Score from the training and validation datasets. These laws are collected from some research papers [8]. Confusion matrix produced based on validation data which include the predicted

level of the dataset and actual class level. The figure will show in the result part section. From the classification report table, we can see the total percentage of precision, recall, and F1 Scores. It will show in the result part section.

From the graphical representation, we can see the total amount of data loss and accuracy. We will try to find out 99% accuracy using a modified VGG-16 model in our research in the future but it will be difficult. Accuracy vs Val accuracy and Loss vs Val loss curves are gained from the trained and validation datasets. These curves are shown for the 10th epochs and for the 20th epochs, where the data loss amount is less than 20% and we think the loss amount will decrease less than 10% at the 100th epochs. In this research, Literature Riview in section II, Research Methodology in section III, Result Analysis in section IV and finally, Future work in section V are discussed sequentially.

## 2. LITERATURE REVIEW

The real-time standard diagnostic tool used is the RT-PCR test. It is mainly to detect COVID-19 cases or any other pathogen system. The process of finding disease and its existing literature system was discussed by R.Sethi et al [9]. Nasopharyngeal is the first step which is collected from the nose or throat of patients. It helps the medical on the epidemic. Some of the cons of the test are the time taken to find out the accurate results. Another way is image X-Ray. The X-Ray image classification is classified by CNN with deep learning techniques. Different lung diseases can find from chest X-Ray images and 21,000 images are used to train the model for diagnosis of the disease [10].Analyze the CBCs report of COVID-19 hematologic. CBCs include some blood cells. These are red blood cells (RBC), white blood cells (WBC), and platelets of blood corpuscles. Measuring every blood cell a decision can take. Using the results of CBC, a COVID-19 positive patient will have 1. Hb ub g/dl 2. ANC, 3. ALC, 4. APC and the ratio of NLR & PLR as cell*103 micro liter [10].YOLO, YOLOV3, YOLOV4 are the real-time object detection algorithm. A binary classification model can use to find a patient who is COVID positive or not using excels datasets. It will give 1 or 0, which means yes or not. It is called the "binary model/Logistic Regression Model" [11]. Some datasets are used to microscopic blood cells containing a total of 364 images. Trained to find better performance, gradient but shown as false YOLOV3 weights. Another way for COVID detection can be done from CT images using Transfer Learning. With the help of the k-means algorithm, ANN and clustering can be done and Faster RCNN models and using VGG-16 model COVID-19 patients can predict [12] [13]. Some research paper uses VGG-16, VGG-19 and U-Net model to find out COVID is positive or Negative using Chest X-Ray images. They classified images into two types. One is COVID positive and another is COVID negative. But they also can use Linear Regression model for this. Their accuracy is ninety percent or more than [14].
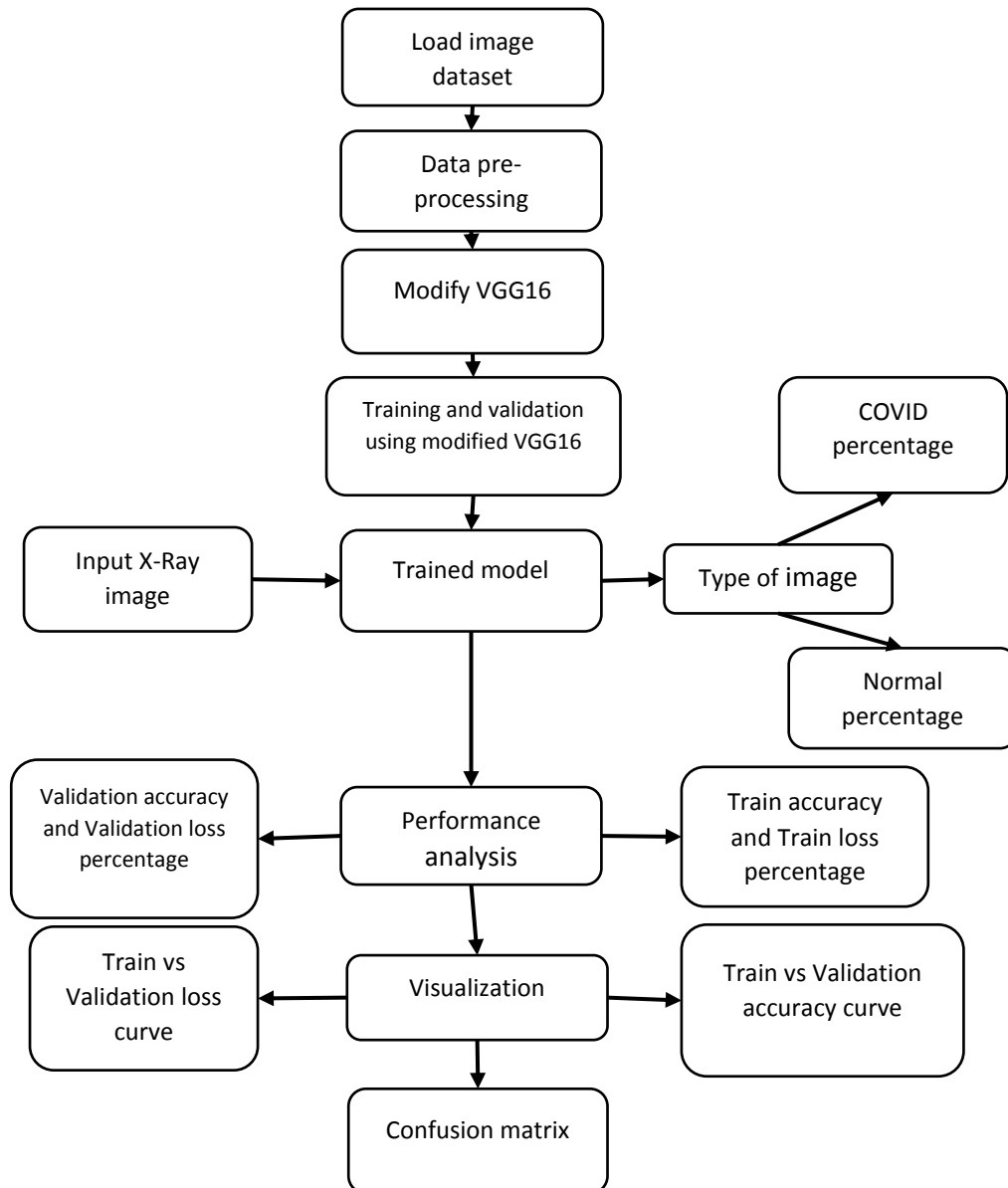
## 3. METHODOLOGY

```
                    ┌──────────────┐
                    │ Load image   │
                    │ dataset      │
                    └──────┬───────┘
                           ↓
                    ┌──────────────┐
                    │ Data pre-    │
                    │ processing   │
                    └──────┬───────┘
                           ↓
                    ┌──────────────┐
                    │ Modify VGG16 │
                    └──────┬───────┘
                           ↓
          ┌──────────────────────────┐        ┌──────────────┐
          │ Training and validation  │        │ COVID        │
          │ using modified VGG16     │        │ percentage   │
          └────────────┬─────────────┘        └──────────────┘
                       ↓
┌──────────────┐  ┌──────────────┐  ┌──────────────┐
│ Input X-Ray  │→ │ Trained model│→ │ Type of image│
│ image        │  └──────┬───────┘  └──────────────┘
└──────────────┘         ↓                    ┌──────────────┐
                                              │ Normal       │
                                              │ percentage   │
                                              └──────────────┘
```

Figure 3.1. Block diagram of proposed system

### 3.1.1 Load Image Dataset

The first step of our proposed methodology is load image dataset. Total 21,165 X-Ray images loaded to a specific folder for the data pre-processing. Image datasets are open source and collected from websites.

### 3.1.2 Data pre-processing

Second step in the methodology system is data pre-processing. Loaded datasets are pre-processed for the model. Data pre-processing system is shown at Figure 3. 2

For the training datasets will be greyscale converted. If the loaded datasets are 3D or color format, then we must convert it into 2D format as greyscale image. Then, we set the size of the images as we want. After conversion of image resize, we can perform data augmentation process Image pre-processing is the term for operations on images at the lowest level of abstraction. These operations do not increase image information content and they decrease it if entropy is on the information measure. The main aim of image pre-processing is the improvement of image data that suppresses undesired distortions [15]. There are four different types of image pre-processing techniques are:

- Pixel brightness transformation or brightness corrections

- Geometric Transformations

- Image Filtering and Segmentation

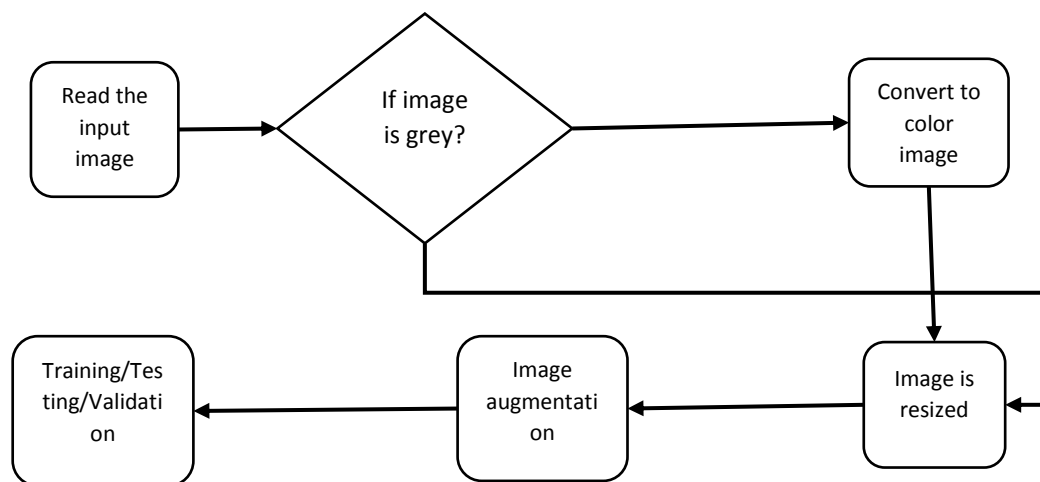- Fourier transformation and Image restauration [16]

**Figure 3.2. Pre-processing of Image**

### 3.1.3 Modify VGG-16

Convolutionl Neural Network (CNN) is the most widely used model for real-life object detection like image classification. VGG-16 is a variant of the CNN model. VGG-16 includes a total of 41 layers but 21 layers were used in proposed method. In our methodology, we modify the VGG-16 model because it gives 92.28% accuracy of image classification. It was one of the famous models in the running world at that time submitted to ILSVRC-2014. It improves on the Alex Net model by replacing large kernel-sized filters (11 and 5 in the first and second convolutional layer, respectively) with multiple 3×3 kernel-sized filters one after another.

VGG-16 was trained for weeks in machine learning and was using NVIDIA Titan Black GPU's [17]. Every image can be connected into Convolution Layer, Max Pooling Layer, and Fully Connected Layer. The commonly used activation functions are ReLU and SoftMax which are used in Convolution Layer and Fully Connected Layer respectively. Both functions are used in Max-Pooling Layer. Max-Pooling Layer reduces the dimension of images [18]. VGG-16 is a CNN model proposed by K.Symonyan as well as A. Zisserman from the oxford university in the paper "Very Deep Convolutional Network for Large-Scale Image Recognition". It was one of the famous models submitted to ELSVCR-2014. A total of 16 layers were used in this model that's why it is called VGG-16. In conv1, input shape 224*224 is fixed. The image is passed through a Convolutional Layer that has a 3*3 filter. Max-Pooling Layer performed with 2*2 image shape. The deep learning architecture, contains the input layer, deep learning layers, and finally output layer which are shown in the Fig. 3.

### 3.1.4 Training and Validation using modified VGG-16

In our proposal system, we trained the dataset using the modified VGG-16 model. Validation also done based on the model. About 17000 images used to trained and about 3000 images for validation. The images categorized in four different types in training and also validation.
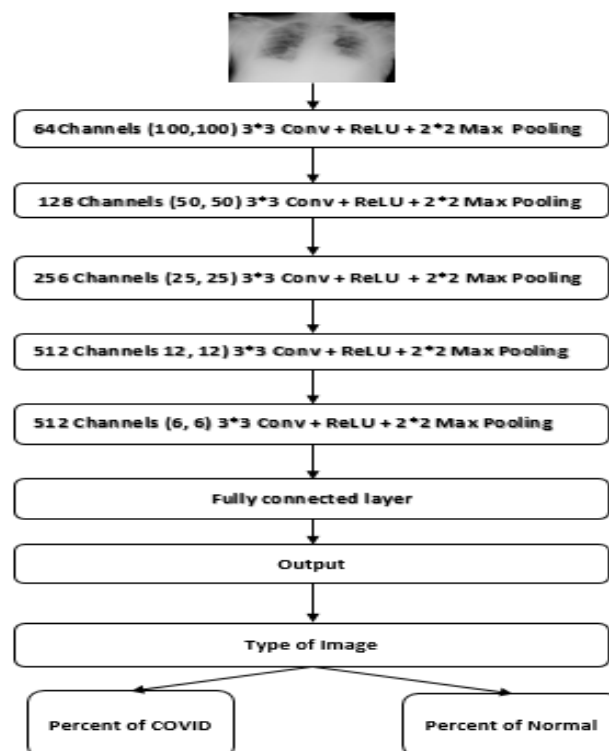


**Figure 3.3 Modified VGG-16 model**

### 3.1.5 Input image

We can give an image as input for the test in our system, Based on trained model, the system can predict the input image and gives an output. At first, the system produces the type of the image such as COVID, pneumonia, normal and lung opacity. Then, it can predict the percentage of COVID possibility and normal possibility of that image, if the percentage is more than 70 percent then we call it COVID positive. Otherwise, it is normal. For the input image any X-Ray image can use. Specially, COVID, normal, lung opacity and pneumonia images can use for better accuracy.

### 3.1.6 Performance Analysis

In our proposed model, the performance of gained model is the best. It can predict two types of results, accuracy vs validation accuracy and loss vs validation loss and finally we get a visualization based on data validation. The loss is less than 20% in the system. Follow the Fig. 7 and Fig. 8 to see the accuracy and data loss at 10th as well as 20th epochs

### 3.1.7 Visualization

In the methodology, last step is the visualization. It has basic three parts,

- Accuracy vs validation accuracy curve
- Loss vs validation loss curve and
- Confusion matrix for the data validation.

## 4. RESULTS AND EVALUATION

### 4.1. Dataset Description

Dataset is the soul of the software module. COVID-19 positive, Normal, Pneumonia, and Lung Opacity image dataset are collected from the Kaggle community, this database is made by medical physicians [19].

**Table 4.1. Dataset Details**

| Dataset Names | Number of Images |
|---|---|
| COVID-19 | 3,616 |
| Normal | 10,192 |
| Pneumonia | 1,345 |
| Lung Opacity | 6,012 |
| Total | 21,165 |

The dataset is developed by the Italian Society of Medical and Invention of Radiology (SIRM) for COVID-19 prediction. Images are collected from different publications with their metadata. All images are under the Portable Network Graphics (PNG) format which is 1024*1024 resolutions. Images are converted into 100*100 pixels as well as 224*224 pixels by CNN. A

CNN is used to build 4 classes to identify COVID, Normal, Pneumonia, and Lung Opacity images. Fig 4.1 shows such 4 types of Chest X-Ray images.
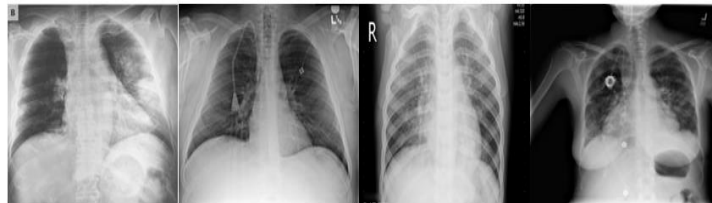


**Figure 4.1.COVID, Normal, Pneumonia and Lung Opacity Images**

In our research, every dataset can be partitioned into two parts. One is training and another is the validation part. Show Table-4.2

**Table 4.2 Dataset details for training and validation part**

| Image Category | Number of training Images | Number of validation images |
|---|---|---|
| COVID | 3,615 | 510 |
| Normal | 10,192 | 1,504 |
| Pneumonia | 1,345 | 248 |
| Lung Opacity | 6,012 | 720 |
| Total | 21,165 | 2,978 |

### 4.2. Evaluation Matrix

We get a matrix named "confusion matrix" based on validation data over the training dataset. Confusion Matrix is used to evaluate the performance of machine learning algorithm (Supervised learning), each row of the confusion matrix represents the actual class levels and each column represents the predicted level based on trained and tested data. We can calculate the accuracy, precision, recall, and F1 score using the equations below [20].

$$\text{Accuracy} = \frac{\text{True}_{\text{Positive}} + \text{True}_{\text{Negative}}}{\text{True}_{\text{Positive}} + \text{True}_{\text{Negative}} + \text{False}_{\text{Positive}} + \text{Falsee}_{\text{Negative}}} \dots\dots\dots\dots\dots (1)$$

$$\text{Precision} = \frac{\text{True}_{\text{Positive}}}{\text{True}_{\text{Positive}} + \text{False}_{\text{Positive}}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$\text{Recall} = \frac{\text{True}_{\text{Positive}}}{\text{True}_{\text{Positive}} + \text{False}_{\text{Negative}}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

$$\text{F1}_{\text{Score}} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (4)$$

Precision indicates that how many of the positive predictions are made are correct. Recall/Sensitivity is used to measure how many of the positive cases the classifier correctly predicted, overall the positive cases in the datasets. F1 Score is a measure of combining precision and recall. It describes the harmonic mean. It is used to measure average value [21]. In our research, the classification report of the normalized confusion matrix is below.

**Table 4.3 Classification Report**

| Classification | Precision | Recall/Sensitivity | F1 Score | Support |
|---|---|---|---|---|
| COVID | 0.21 | 0.20 | 0.20 | 511 |
| Lung Opacity | 0.23 | 0.24 | 0.23 | 721 |
| Normal | 0.49 | 0.49 | 0.49 | 1,505 |
| Pneumonia | 0.10 | 0.10 | 0.10 | 245 |
| Accuracy | | | 0.35 | 2982 |
| Macro avg: | 0.26 | 0.26 | 0.26 | |
| Weighed avg | 0.35 | 0.35 | 0.35 | |

Fig. 6 shows the confusion matrix of the predicted datasets over the training and testing datasets. It shows the percentage of the predicted data with true levels over the training and testing dataset. It has four classification percentages like COVID, lung opacity, normal and viral pneumonia, whose report shown in table 5.3 (see above). The highest predicted value is 48% the and lowest predicted value is 6% in the confusion matrix. Macro average accuracy is 25% and the weighted average is 35% (see TABLE-III).

## 4.3. Results and Analysis

Using the modified VGG-16 model highest accuracy is obtained. Confusion matrix is used for correction and incorrect prediction [22]. Data visualization is important in accurate results. In visualization, we have two basic parts: evaluate the underfitting and evaluate the Overfitting [23].

## 4.4 X-Ray Image Analysis

In our study, the model accuracy is higher than 90.28%. The system can produce a percentage of COVID and Normal from an input image. Fig. 5 indicates that input and output image. After heat map, the system can predict the percent of COVID and Normal possibility from that image. Table-4.2 illustrates the result of X-Ray images from Figure 4.2

**Figure 4.2 COVID, Normal, Pneumonia and Lung Opacity images to find COVID**

| SL | Image Type | Disease Type | COVID percentage | Normal Percentage |
|---|---|---|---|---|
| (a) | Original | COVID | | |
| (b) | Heat Mapped | COVID | 90.24% | 9.44% |
| (c) | Original | Normal | | |
| (d) | Heat Mapped | Normal | 0.05% | 84% |
| (e) | Original | Viral Pneumonia | | |
| (f) | Heat Mapped | Viral Pneumonia | 0.018% | 0.066% |
| (g) | Original | Lung Opacity | | |
| (h) | Heat Mapped | Lung Opacity | 0.02% | 99% |

**possibility**



(a) COVID    (b) COVID Output    (c) Normal    (d) Normal Output

(e) Pneumonia    (f) Pneumonia Output    (g) Lung Opacity    (h) Lung Opacity Output
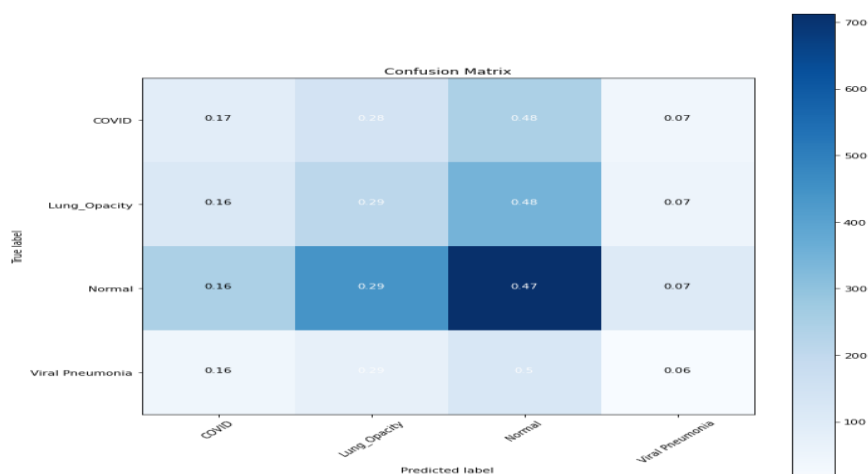
**Table 4.4 X-Ray image analysis results**



**Figure 4.3 Confusion Matrix for data validation**

### 4.4.1 Accuracy and Loss graphical representation

Accuracy vs validation accuracy and loss vs validation loss graphical representation are below. In the Figure 4.4 and Figure 4.5, we see the accuracy vs validation accuracy is above 90% and loss vs validation loss is inversely decremented. Loss vs validation loss is very rare. The green color indicates accuracy and the red color is used for the validation part in the graph. The loss starts from 60% for loss and 45% for validation loss at the first epoch but it is a decrement process. The loss is less than 26% at the 10th epoch and validation loss is less than 20% at the same epochs. The testing graph is also the same as validation. The same graph at the 20th epochs.
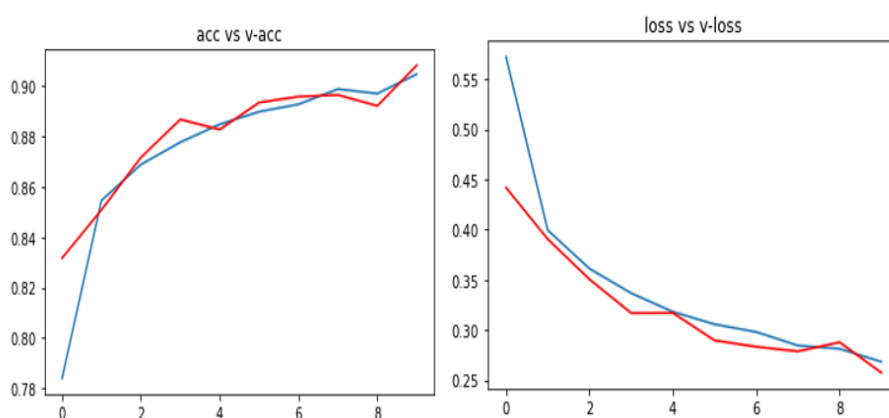


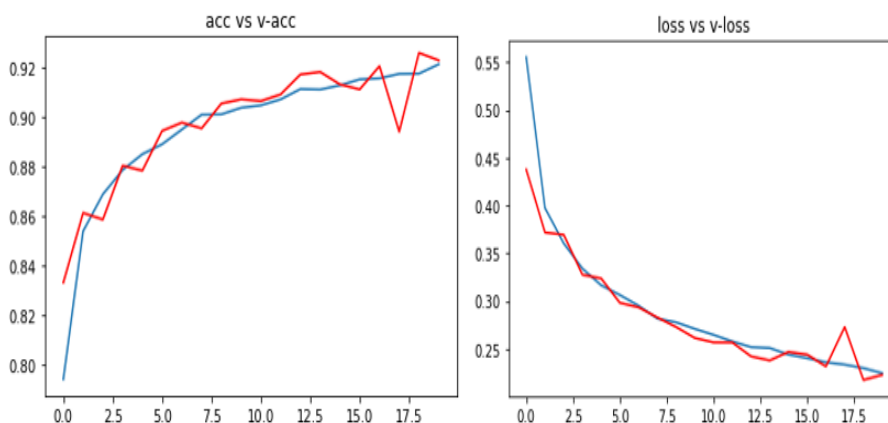**Figure 4.4 Comparison Curve at 10$^{th}$ epoch**



**Figure 4.5 Comparison Curve at 20th epoch**

## 5. CONCLUSION

In this research, we have proposed a system to recognize COVID-19 from chest X-Ray images using modified VGG-16 architecture. We used a dataset named COVID-19 Radiography dataset from Kaggle which is consists of almost 21,000 images with four categories. The proposed model performance is evaluated using this dataset. Along with COVID-19 our model is also able to recognize viral pneumonia, lung opacity and normal chest. The recognition rate of our proposed system is 92.28%. Our future research will be focused on recognizing COVID-19 also from CT-Scan images and we will try to use advanced deep learning algorithm to detect the COVID-19.

**References**

1) W. H. Organization, "WHO Coronavirus (COVID-19) Dashboard," WHO Health Emergency Dashboard, 7 January 2022.

2) Online, "Worldometer," Countries where COVID-19 has spread, 7 January 2022.

3) Z. E. Staff, ""What are the symptoms of Omicron?," 18 January 2022.

4) J. D. N. T. D. Sikder, "A Deep Learning Approach for Recognizing Covid-19 from Chest X-ray using Modified CNN-BiLSTM with M-SVM.," in International Conference on Electrical, Computer and Energy Technologies (ICECET), July 2022.

5) T. R. A. K. a. R. M. M. E. H. Chowdhury, "Can AI Help in Screening Viral and COVID-19 Pneumonia?," vol. 8, pp. 132665 - 132676, 2020.

6) R. Thakur, "Step by step VGG16 implementation in Keras for beginners," Towards Data Science, 06 August 2019. [Online]. Available: https://towardsdatascience.com/step-by-step-vgg16-implementation-in-keras-for-beginners-a833c686ae6c.

7) K. I. S. K. D. Juel Sikder, "Fish Disease Detection System: A Case Study of Freshwater Fishes of Bangladesh," International Journal of Advanced Computer Science and Application, vol. 12, 6 Novemver 2021.

8) U. K. D. J. C. Juel Sikder, "Supervised-Learning cancer detection," International Journal of Advanced Computer Science and Application, vol. 12, 5 November 2021.

9) M. D. R.Sethi, "Deep Learning Based Dignosis Recommendations for COVID-19 Using Chest X-Ray Images," Inventive Research in Computing Applications, 2020.

10) S. K. Gothwal, "Complete Blood-count-based Inflammatory Score (CBCS) of COVID-19 Patients at Tertiary Care Center," National Liabrary for Medicine, Vols. 18-24, 27 January 2021.

11) A. D. S. Hossain, "Symptoms Based COVID-19 Detection Model Using Logistic Regression Model," IOSR Journal of Computer Engineering (IOSR-JCE), vol. 23, pp. 2278-8727, June 2021.

12) A. H. B. Datta, "COVID-19 detection from lung CT-scan images," Machine Learning: Science and Technology, vol. 2, no. 45013, pp. 2632-2153, March 2021.

13) T. S. J. C. R. F. J. Mahmud, "Fabric defect Detection System. Intelligent Computing and Optimization," Advances in Intelligent Systems and Computing, vol. 1324, 2020.

14) VayadOscarCardona-MoralesaReinelTa, "COVID-19 Detection in X-Ray images using convolutional neural networks," Elsevier, vol. 6, pp. 100-138, December 2021.

15) J. D. N. T. S. D. U. K. Sikder, "Emotion, Age and Gender Recognition using SURF, BRISK, M-SVM and Modified CNN," in International Conference on Electrical, Computer and Energy Technology (IEEE), July 2022.

16) G. Learning, "Introduction to Image Pre-processing," 24 October 2022. [Online]. Available: https://www.mygreatlearning.com/blog/introduction-to-image-pre-processing/.

17) Neurohive, "VGG16 – Convolutional Network for Classification and Detection," 20 November 2018. [Online]. Available: https://neurohive.io/en/popular-networks/vgg16/.

18) D. CORNER, "Max Pooling in Convolutional Neural Network and Its Features," March 2020. [Online]. Available: https://analyticsindiamag.com/max-pooling-in-convolutional-neural-network-and-its-features/.

19) k.team, "kaggle," [Online]. Available: https://www.kaggle.com/tawsifurrahman/covid19radiography-database.

20) T. Kanstrén, "A Look at Precision, Recall, and F1-Score," 12 September 2020. [Online]. Available: https://towardsdatascience.com/a-look-at-precision-recall-and-f1-score-36b5fd0dd3ec.

21) A. Gad, "Evaluating Deep Learning Models: The Confusion Matrix, Accuracy, Precision, and Recall," 19 February 2021. [Online]. Available: https://www.kdnuggets.com/2021/02/evaluating-deep-learning-models-confusion-matrix-accuracy-precision-recall.html.

22) B. A. F. Gad, "Evaluating Deep Learning Models: The Confusion Matrix, Accuracy, Precision, and Recall," 2020. [Online]. Available: https://blog.paperspace.com/deep-learning-metrics-precision-recall-accuracy/.

23) V. Sharma, "PLURALSIGHT," 14 June 2019. [Online]. Available: https://www.pluralsight.com/guides/da.

24) Z. E. Staff, "What are the symptoms of Omicron?," 18 January 2022.

25) M. E. H. Chowdhury, T. Rahman, A. Khandakar and R. Mazhar, "Can AI Help in Screening Viral and COVID-19 Pneumonia?," IEEE, vol. 8, pp. 132665 - 132676, 2020.

26) R. Thakur, "Step by step VGG16 implementation in Keras for beginners," Towards Data Science, pp. Available on online: https://towardsdatascience.com/step-by-step-vgg16-implementation-in-keras-for-beginners-a833c686ae6c, 201.

27) G. L. Team, "Great Learning," 17 August 2020. [Online]. Available: https://www.mygreatlearning.com/blog/introduction-to-image-pre-processing/.

28) neurohive, 20 November 2018. [Online]. Available: https://neurohive.io/en/popular-networks/vgg16/.

29) 20 March 2020. [Online]. Available: https://analyticsindiamag.com/max-pooling-in-convolutional-neural-network-and-its-features/.