

CovidAID: COVID-19 Detection using Chest X-Ray Images

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Abstract- The detection of extreme acute respiration syndrome coronavirus, which is accountable for coronavirus sickness 2019, using chest X-ray snap shots has life-saving significance for both sufferers and medical doctors. on this examine, we aimed to give the usage of deep learning for the excessive-accuracy detection of COVID-19 the use of chest X-ray pics. Thirty-eight experiments have been finished the usage of convolutional neural networks, 10 experiments had been finished the use of 5 device studying models, and 14 experiments have been completed the usage of the nation of the art pre-educated networks for switch learning. A convolutional neural community without pre-processing and with minimized layers is capable of detecting COVID-19 in a restricted range of, and in imbalanced, chest X-ray pictures.

Key Words: COVID-19, Pneumonia, X-Ray Images Datasets, Convolutional Neural Networks, Artificial Intelligence & Machine Learning.

1. INTRODUCTION:

Even as the COVID-19 outbreak started out in Wuhan, China, the substantial unfolded latest the epidemic around the sector has intended that the amount state-of-the-art device available to doctors fighting the disorder is insufficient. in step with a currently posted multinational consensus declaration with the aid of the Fleischner Society, one of the predominant suggestions is to use chest radiography for sufferers with COVID-19 in a aid-limited surroundings whilst get entry to to computed tomography is confined. the usage of X-ray pics for the automated detection state-of-the-art COVID-19 might be beneficial in particular for countries and hospitals which can be unable to purchase a laboratory package for assessments or that do not have a CT scanner. On this look at, 1583 regular, 4292 pneumonia-inflamed, and 225 COVID-19-inflamed unique and pre-processed public X-ray snap shots had been taken into consideration for the prognosis contemporary COVID-19 the usage of the exceptional architectures latest the maximum widely used picture reputation ConvNet networks. In line with their formerly cited announcement, the Fleischner Society recommends that scientific practitioners use chest X-ray and CT in the control modern COVID-19.

2. MATERIALS and METHODS:

2.1 DATASETS:

The average age for the COVID-19 group turned into 58.8±14.9 years, and it comprised 131 male sufferers and 64 female sufferers. notice that some sufferers' records are missing; that is because the dataset used in this study does now not have accompanying whole metadata, due to the fact that is the very first publicly to be had COVID-19 X-ray photograph series, and it becomes created in a constrained time. in addition, 1583 normal and 4292 pneumonia chest X-ray photos have been obtained from Kermany et al. All photographs have been in unique dimensions, in order that they have been resized to 640x480.

2.2 DESIGN of EXPERIMENTS:

Several categorized experiments had been completed to assess the performance of the ConvNet on the considered photograph database and to compare ConvNet with different models using the fundamental statistical characteristics of the pictures, which could offer powerful records for category. Experiments are divided into three classes: ConvNet Experiments, Statistical Dimension Experiments, Transfer Learning Experiments.

2.3 ConvNet EXPERIMENTS:

They blanketed the usage of four exceptional network architectures with various numbers of convolutional and fully related layers, and primary photograph pre-processing strategies to check the effects the use of numerous systems and pre-processing strategies. ConvNet which changed into the deepest structure in this examine, consisted of four convolutional layers and three absolutely connected layers.

Table 1. Architectural Properties of Four Considered ConvNets.

Architecture Name	ConvNet Layer No.	Filters	Filter Size	Pooling and Size	Dropout	Activation
ConvNet#1	ConvNet Layer 1	64	3×3	Max-pooling 2×2	0.2	ReLU
	ConvNet Layer 2	16		Max-pooling 1×1		
ConvNet#2	ConvNet Layer 1	128	3×3	Max-pooling 2×2	0.2	ReLU
	ConvNet Layer 2	64		Max-pooling 1×1		
ConvNet#3	ConvNet Layer 1	256	3×3	Max-pooling 2×2	0.2	ReLU
	ConvNet Layer 2	128		Max-pooling 1×1		
ConvNet#4	ConvNet Layer 1	256	3×3	Max-pooling 2×2	0.2	ReLU
	ConvNet Layer 2	128				
	ConvNet Layer 3	64				
	ConvNet Layer 4	64				

ConvNet: Convolutional neural network; ReLU: rectified linear unit.

Table 2. ConvNet Experiments and General Properties.

Experiment No.	ConvNet Architecture	Input Dimension	Pre-Processing	Dense Layer #1	Dense Layer #2	Dense Layer #3
Exp.1	ConvNet#1	160×120	Sharpening	128	8	—
Exp.2	ConvNet#2	160×120	Sharpening	128	8	—
Exp.3	ConvNet#3	160×120	Sharpening	128	8	—
Exp.4	ConvNet#4	160×120	Sharpening	128	64	8
Exp.5	ConvNet#1	30×20	Sharpening	128	8	—
Exp.6	ConvNet#2	30×20	Sharpening	128	8	—
Exp.7	ConvNet#3	30×20	Sharpening	128	8	—
Exp.8	ConvNet#1	30×20	APPN	128	8	—
Exp.9	ConvNet#2	30×20	APPN	128	8	—
Exp.10	ConvNet#3	30×20	APPN	128	8	—
Exp.11	ConvNet#1	160×120	—	128	8	—
Exp.12	ConvNet#2	160×120	—	128	8	—
Exp.13	ConvNet#3	160×120	—	128	8	—
Exp.14	ConvNet#4	160×120	—	128	64	8
Exp.15	ConvNet#1	30×20	—	128	8	—
Exp.16	ConvNet#2	30×20	—	128	8	—
Exp.17	ConvNet#3	30×20	—	128	8	—

APPN: Average pixel per node; ConvNet: convolutional neural network.

A total of 34 experiments have been carried out on this category, 17 each of COVID-19/ordinary and COVID-19/Pneumonia, to evaluate and analyze the performance of ConvNets below distinctive conditions to acquire a finest classification of COVID-19 pics. The COVID-19/Pneumonia/everyday experiments have been accomplished by thinking about the premier results received within the different classes, and 4 experiments had been carried out.



2.4 STATISTICAL DIMENSION EXPERIMENTS:

Every photograph hides primary statistical records this is beneficial for gadget gaining knowledge of fashions. consideration of the constrained wide variety of values as opposed to pics decreases the computational time while attaining affordable effects. on this research, primary statistical data and the pre-processed traits have been received from the images. Then, the picture changed into divided into 3 segments vertically, and the middle one was the widest in order not to divide the location of hobby. This method changed into done to dispose of the corners and borders in the image.

Table 3. Description of Feature Vectors Created from X-Ray Images.

Attribute	Description
Lower	Total number of pixel values smaller than $[\max(p)/2]$
Higher	Total number of pixel values greater than $[\max(p)/2]$
LMean	Mean of the left segment of image
CMean	Mean of the center segment of image
RMean	Mean of the right segment of image
MeanLP	Mean of the Laplacian filter
MeanSh	Mean of the sharpened image
MeanHE	Mean of the histogram equalization applied image
Min	Minimum pixel value within the image
Max	Maximum pixel value within the image
Entropy	Entropy of the image
StdDev	Standard deviation of the image
Var	Variance of the image
Mode	Pixel value that is the most frequent within the image

2.5 TRANSFER LEARNING EXPERIMENTS:

VGG16 is a CNN architecture that has 16 layers with weights and uses 3three filters. After convolutional layers, it has two absolutely connected layers, observed via a softmax for output. ResNet50 has 50 residual layers, which goal to solve issues which include time consumption whilst the community turns into deeper. It factorizes convolutions to lessen the variety of parameters without lowering the community performance. MobileNet-V2 has 53 layers and extra than 3.4 million trainable parameters. It includes residual connections and growth, depthwise, and projection convolutions.

2.6 MODEL EVALUATION CRITERIA:

In clinical programs, the version with the higher ROC AUC rating is extra able to distinguishing between patients with COVID-19 and without COVID-19 and outcomes are the responses of the outputs obtained from the model.

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

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

$$\text{Specificity} = \frac{TN}{TN+FP}$$

All experiments had been accomplished with the aid of k-fold go-validation, that is based totally on dividing all the records right into a predefined variety of folds, k, and the usage of onefold for checking out and the remaining for training. on this have a look at, eightfold move-validation turned into used for checking out. The range of pix inside the validation set turned into restrained so as now not to lessen the range of pics within the inflamed elegance. On the cease of statistical dimension, COVID-19/regular, and COVID-19/Pneumonia experiments, the mean accuracy, mean specificity, imply sensitivity, and the suggest ROC AUC scores were calculated, and all the opinions had been achieved at the mean scores.

3.RESULTS:

3.1 RESULTS OF ConvNet EXPERIMENTS:

3.1.1 RESULTS OF COVID-19/NORMAL EXPERIMENTS:

the very best suggest accuracy of Experiments 1–7 turned into received in Exp. the best suggest sensitivity, maximum mean specificity, and maximum suggest ROC AUC rating, that's the number one indicator for an imbalanced dataset, however, were received in Exp. In the APPN-implemented experiments, at the same time as the better mean accuracy, higher mean sensitivity, and higher ROC AUC score were obtained in Exp. 8, the better imply specificity turned into carried out in Exp.

17, in which unique photographs had been used with specific dimensions in distinctive ConvNet architectures, regular charges have been obtained for mean accuracy and suggest specificity. modifications in the prices of suggest sensitivity and suggest ROC AUC rankings have been, however, acquired using the unique architectures. the best imply accuracy and maximum mean specificity have been obtained in Exp. the highest imply sensitivity and maximum mean ROC AUC ratings for the COVID-19/ordinary organization had been accomplished in Exp.

Table 4. Results Obtained for COVID-19/Normal and COVID-19/Pneumonia Classification.

Experiment	COVID-19/Normal				COVID-19/Pneumonia			
	Mean Sensitivity (%)	Mean Specificity (%)	Mean Accuracy (%)	Mean ROC AUC (%)	Mean Sensitivity (%)	Mean Specificity (%)	Mean Accuracy (%)	Mean ROC AUC (%)
Exp.1	91.05	99.61	98.33	95.33	89.77	99.58	99.09	94.67
Exp.2	87.55	99.32	97.05	92.70	88.00	99.60	99.02	93.80
Exp.3	90.98	99.37	98.34	95.17	89.33	99.51	99.00	94.42
Exp.4	86.63	99.60	98.05	92.00	85.33	99.67	98.95	92.50
Exp.5	90.12	98.42	97.40	94.27	87.55	99.51	98.91	93.53
Exp.6	86.88	98.05	96.78	93.66	85.33	99.44	98.73	92.38
Exp.7	89.19	99.23	98.00	94.21	84.88	99.32	98.60	92.00
Exp.8	91.84	98.98	98.23	95.41	84.44	99.62	98.87	92.03
Exp.9	87.33	98.97	97.13	93.69	85.33	99.37	98.67	92.35
Exp.10	88.67	99.29	97.95	93.98	88.00	99.51	98.93	93.75
Exp.11	93.84	99.18	98.50	96.51	92.88	99.79	99.44	96.33
Exp.12	88.37	99.57	98.91	93.89	87.11	99.62	99.00	93.36
Exp.13	87.88	98.98	97.73	93.43	87.11	99.62	99.00	93.36
Exp.14	89.12	99.78	99.11	94.57	85.77	99.18	98.51	92.48
Exp.15	90.10	99.50	98.34	94.80	90.22	99.67	99.20	94.94
Exp.16	84.11	98.80	97.64	91.01	86.22	99.60	98.93	92.91
Exp.17	87.71	99.11	97.73	93.41	86.22	99.48	98.82	92.85

COVID-19: Coronavirus disease 2019; ROC AUC: receiver operating characteristics-area under the curve.

3.1.2 RESULTS OF COVID-19/PNEUMONIA EXPERIMENTS:

Even though the wide variety of education snap shots become extended, and the second education set is a hard dataset for detecting COVID-19, similar effects to the ones inside the COVID-19/regular experiments had been obtained. When the photos fed ConvNets immediately, we discovered that the increment of the convolutional layer wide variety of ConvNets reduces the ratings acquired by the neural community as much as 4%, just like COVID-19/regular effects.

3.1.3 RESULTS OF COVID-19/PNEUMONIA/NORMAL EXPERIMENTS:

within the remaining group of ConvNet experiments, a complete of 6100 photographs had been educated in every experiment for three output instructions as COVID-19, ordinary, and Pneumonia. because superior outcomes have been acquired without photograph pre-processing in COVID-19/normal and COVID-19/Pneumonia experiments, the experiments in this group were executed using best the unprocessed pics with a hundred and sixty hundred and twenty dimensions with four taken into consideration ConvNet architectures. The effects received by means of ConvNet no 1 have been similar to ConvNet#3 results, and the macro-averaged F1 score become 92.84%. ConvNet#4, with the private shape, produced comparable results to ConvNet#2 however could not outperform it.

Table 5. Results Obtained for COVID-19/Pneumonia/Normal Classification.

Model	Mean Precision (%)			Mean Recall (%)			Mean Accuracy (%)	Macro-Averaged F1 Score (%)
	Corona	Normal	Pneumonia	Corona	Normal	Pneumonia		
DenseNet121	98.87	90.90	88.52	95.66	97.20	92.03	95.99	93.85
InceptionV3	97.76	90.99	86.54	95.99	96.54	91.16	94.90	93.14
ConvNet#1	96.20	93.72	92.98	97.45	86.22	90.63	95.26	92.84
ConvNet#2	96.77	95.27	93.05	97.41	90.04	92.12	95.75	94.10
ConvNet#3	96.26	93.15	92.26	96.98	86.79	90.88	95.04	92.70
ConvNet#4	97.51	91.42	92.32	96.90	92.69	93.49	95.88	94.04

ConvNet: Convolutional neural network; COVID-19: coronavirus disease 2019.

3.2 RESULTS OF STATISTICAL DIMENSION EXPERIMENTS:

5 experiments have been done for COVID-19/regular category by using considering 14 features received from the photos and the usage of 5 machine studying classifiers: SVM, LR, nB, DT, and kNN. Inconsistent results were acquired for kNN and nB. kNN performed the very best imply specificity charge (99.95%), but it also produced the lowest mean sensitivity and lowest suggest ROC AUC score (63.10 and 81.33%, respectively). in addition, nB produced the very best imply sensitivity charge and imply ROC AUC score (eighty two.ninety five and ninety two.seventy five%, respectively), but it produced the lowest imply accuracy and imply specificity rates (93.97 and 94.05%, respectively). SVM accomplished the best mean accuracy result (96.57%). None of those fashions, but, changed into able to outperforming the ConvNet for any of the assessment metrics the usage of the received statistical information.

Table 6. Results Obtained in Statistical Measurement Experiments.

Experiment	COVID-19/Normal				COVID-19/Pneumonia			
	Mean Sensitivity (%)	Mean Specificity (%)	Mean Accuracy (%)	Mean ROC AUC (%)	Mean Sensitivity (%)	Mean Specificity (%)	Mean Accuracy (%)	Mean ROC AUC (%)
SVM	81.30	98.80	96.57	90.05	75.55	97.85	96.74	86.70
Logistic Reg.	68.36	98.12	94.41	83.24	66.66	96.45	94.97	81.56
Decision Tree	75.91	96.53	93.97	87.10	69.77	96.50	95.17	83.14
Naive Bayes	82.95	94.05	93.97	92.75	80.00	97.85	96.96	88.92
kNN	63.10	99.55	95.02	81.33	64.44	96.22	94.64	80.33

COVID-19: Coronavirus disease 2019; kNN: k-nearest neighbor; ROC AUC: receiver operating characteristics-area under the curve (AUC); SVM: support vector machine.

The equal device mastering classifiers and capabilities have been taken into consideration for the classification of COVID-19/Pneumonia. comparable results have been obtained inside the experiments, and nB produced the very best imply ROC AUC, mean sensitivity, and imply accuracy ratings (88.92, 80.00, and 96%, respectively) for statistical size experiments of COVID-19/Pneumonia type. the best imply specificity become received by way of nB and SVM (97.85% each). despite the fact that comparable outcomes have been received in COVID-19/normal and COVID-19/Pneumonia experiments, the decrement within the type levels become located for all system mastering algorithms. This might be caused by both photograph training having ailment and the increment of the number of training pix.

3.3 RESULTS OF TRANSFER LEARNING EXPERIMENTS:

Much like ConvNet experiments, switch learning experiments had been additionally executed in three businesses as COVID-19/ordinary, COVID-19/Pneumonia, and COVID-19/Pneumonia/regular. The two models that could produce superior results within the COVID-19/normal and COVID-19/Pneumonia corporations were taken into consideration in COVID-

19/Pneumonia/normal experiments. Within the COVID-19/everyday institution, VGG19 and MobileNet-V2 produced the worst results. They were only capable of examine one elegance and couldn't classify COVID-19 X-ray snap shots.

Table 7. Results Obtained in Transfer Learning Experiments for COVID-19/Normal and COVID-19/Pneumonia Classification.

Exp.	COVID-19/Normal				COVID-19/Pneumonia			
	Mean Sensitivity (%)	Mean Specificity (%)	Mean Accuracy (%)	Mean ROC AUC (%)	Mean Sensitivity (%)	Mean Specificity (%)	Mean Accuracy (%)	Mean ROC AUC (%)
VGG16	46.04	99.24	92.64	72.64	77.33	99.65	98.53	88.49
VGG19	08.03	100.0	88.55	54.01	70.66	99.48	98.05	85.07
InceptionV3	90.14	99.17	98.17	94.66	89.77	99.65	99.15	94.71
MobileNet-V2	08.40	100.0	87.61	54.20	68.88	99.39	97.87	84.14
ResNet50	31.57	100.0	91.15	45.78	59.55	100.0	97.98	79.77
DenseNet121	93.92	99.04	98.39	96.48	92.44	99.46	99.11	95.95

COVID-19: Coronavirus disease 2019; ROC AUC: receiver operating characteristics- area under the curve (AUC).

Inside the COVID-19/Pneumonia organization, comparable results were received. despite the fact that the VGG19, MobileNet-V2, and ResNet50 improved their scores, they had been no longer able to reach the rankings of DenseNet121 and Inception V3. the very best imply ROC AUC score of COVID-19/Pneumonia class inside the switch mastering test turned into performed through DenseNet121 (95.95%), and it became observed via Inception V3 (94.71%).

After thinking about the effects obtained in the first two businesses, we carried out DenseNet121 and Inception V3 for the classification of COVID-19/Pneumonia/regular. even though fluctuating outcomes were found for precision and recall scores for the COVID-19, Pneumonia, and ordinary instructions, DenseNet121 outperformed Inception V3 in switch getting to know experiments by means of acquiring a macro-averaged F1 rating of 93.85%, at the same time as Inception V3 done 93.14%.

4. COMPARISONS OF EXPERIMENTS:

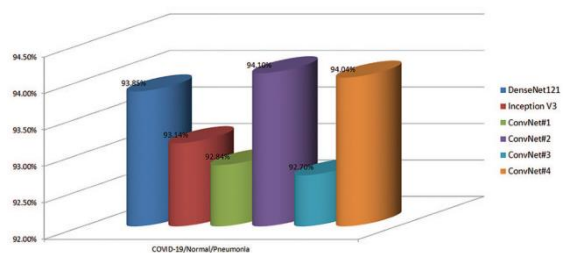
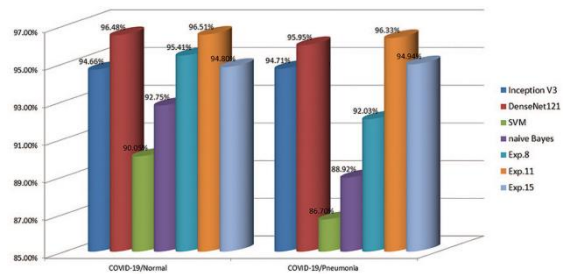
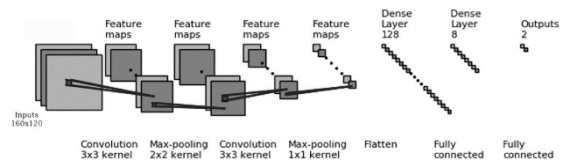
The best suggest sensitivity was finished by way of DenseNet121, however different received ratings had been now not excessive enough to outperform other fashions in different metrics. despite the fact that ConvNetnumber 1 could not produce the most desirable effects in sensitivity, specificity, and accuracy results, its stability produced steady outcomes, and the very best imply ROC AUC score become achieved through ConvNetnumber 1 with 96. device gaining knowledge of classifiers could not produce high-quality outcomes the use of the extracted statistical information to categorise COVID-19 on this experimental institution. In COVID-19/Pneumonia class, further to the previous experiments, the highest suggest ROC AUC score become received in Exp.

Table 8. TP, FP, TN, and FN results for Exp.11 and DenseNet121 for all test folds.

COVID-19/Normal				
Experiment	TP	FP	TN	FN
Exp.11	211	15	1568	14
Densenet121	209	13	1572	14

COVID-19/Pneumonia				
Experiment	TP	FP	TN	FN
Exp.11	209	9	4283	16
Densenet121	208	23	4269	17

COVID-19: Coronavirus disease 2019; FN: false negative; FP: false positive; TN: true negative; TP: true positive.



5. DISCUSSIONS:

In -magnificence experiments, a spread present day image pre-processing strategies have been implemented with extraordinary picture sizes and 4 ConvNet architectures to offer the highest detection accuracy today's COVID-19 in chest X-ray pictures. In COVID-19/normal classification experiments, it turned into tremendously less difficult to categorise COVID-19 due to the fact the ordinary X-ray photographs do no longer contain any abnormalities. the use of the snap shots with decreased dimensions prompted the imply ROC AUC scores modern day the experiments to lower by using about five. a probable answer is feeding the ConvNet with photos with expanded dimensions.

Experimental outcomes showed that using greater convolutional and completely related layers could not enhance the version performance for the photo database taken into consideration, due to the fact the variations among the suggest ROC AUC scores trendy the ConvNet with minimized layers and the ConvNet with extra layers have been greater than 1.7-5%, relying on the pre-processing approach. The minimum mean ROC AUC score contemporary ConvNet with extra layers in APPN-applied photographs become 93.69%, whilst ConvNet#1 executed 95. The number modern-day pictures used within the experiments has an instantaneous impact at the variety ultra-modern layers and the structure ultra-modern the ConvNet, however the obtained effects recommend that using minimized layer numbers can decorate detection trendy COVID-19 within the ordinary pix.

Further to the above-mentioned statistical measurements, the photo pre-processing strategies were applied, and

further measurements have been acquired from the pix to make the expertise for the gadget modern-day fashions as similar as viable to that for the ConvNets. The machine cutting-edge models, however, could not obtain suggest ROC AUC ratings as high as those modern-day the ConvNets, and there was a four% distinction between the very best imply ROC AUC rating in ConvNet experiments and nB, which produced the highest bring about statistical measurement experiments. The usage of transfer ultra-modern with the 49a2d564f1275e1c4e633abc331547db pre-skilled ConvNets turned into also taken into consideration in COVID-19/ordinary classification experiments. The opposite classification kind in this examine become the detection modern COVID-19 in the pneumonia pix.

The same experiments were completed as with COVID-19/everyday experiments, and comparable results had been received. The lightest ConvNet outperformed the other considered ConvNet systems and pre-educated fashions, even though the quantity present day schooling samples accelerated present day the variety state-of-the-art photographs within the dataset. in addition, device trendy classifiers have been no longer able to produce better results than ConvNets acquired, but general reduction become discovered inside the category performance today's system modern day fashions. This was due to the complexity trendy pictures, the difficulty contemporary differentiating COVID-19 from pneumonia pictures, and the improved range present day schooling samples.

In three-magnificence experiments, the increment modern day the elegance number and the education samples brought about ConvNetno 1 to no longer produce top-rated effects. The increment ultra-modern the range contemporary output training and schooling samples, however, calls for a deeper shape for powerful ultra-modern. COVID-19 data used on this take a look at were collected by using pulling pictures from guides and websites. X-ray imaging parameters might be one of a kind for modern day the scans, which would possibly bring about specific picture pleasant, and this is commonplace when multisite studies are combined, or one database has multiple feature flaws like extraordinary imaging protocols.

Consequently, pre-processing state-of-the-art the data to make the radiographic photos extra similar and uniform is vital in phrases modern-day offering extra green evaluation and consistency. We consider that, as extra pre-processed datasets on COVID-19 grow to be publicly to be had, more correct studies will be conducted. however, the contemporary constrained dataset has led researchers around the world to develop methods to aid in facilitating the prognosis trendy COVID-19. even though this take a look at indicates that CNNs may be used for automatic detection trendy COVID-19 and for distinguishing it from pneumonia, we accept as true with making use of synthetic neural networks to COVID-19 detection greater as it should be calls for clinical trials.

On the time modern-day writing, there may be no different dependable publicly available dataset. To have a greater accurate and robust model, a larger COVID-19 dataset is wanted.

6. CONCLUSIONS:

The effects confirmed that the convolutional neural community with minimized convolutional and fully linked layers is capable of detecting COVID-19 pics within the two-elegance, COVID-19/ordinary and COVID-19/Pneumonia classifications, with imply ROC AUC scores contemporary 96.51% and 96.33%, respectively. in addition, the second one proposed structure, which had the second one-lightest architecture, is capable of detecting COVID-19 in three-class, COVID-19/Pneumonia/ordinary images, with a macro-averaged F1 rating modern-day 94.10%. consequently, using AI-primarily based automated high-accuracy technology might also provide valuable assistance to medical doctors in diagnosing COVID-19.

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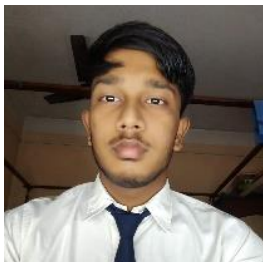


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