

Leveraging X-Ray and CT Scans for COVID-19 Infection Investigation Using Deep Learning Models: Challenges and Research Directions



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1 Introduction

COVID-19 pandemic is threatening the world, and health care bodies are facing challenges to treat coronavirus infected patients. COVID-19 symptoms include fever, cough, and shortness of breath with possible abdominal symptoms and exhibits asymptomatic symptoms in many cases. The radiology is a helpful technology in analyzing chest X-ray and CT image to inspect lung infection. Chest CT scans and X-ray play significant role in detecting and assessing the severity of COVID-19 infection and evaluating the patient response for the treatment given [1, 2]. The COVID-19 is contagious and therefore posed tough challenges to mitigate the spread of infection. The corona virus infection is proven to be life threatening and inflicted great fear in the minds of people across the world. In the context of Indian culture, people across the country offered prayers together and manifested their belief in facing coronavirus threat through customs lighting the lamps, and thanksgiving was offered to care takers by hand clapping by entire nation.

Figure 1 shows various strategies to mitigate corona virus infection, its impact on the workload of health care and law enforcement professionals and outlines the scope for deep learning techniques for COVID-19 pneumonia infection diagnosis.

Artificial intelligence (AI) support in analyzing chest X-ray and CT scans reduces the burden on radiologist and eliminates inaccuracies induced by extraordinary workload. Therefore, there is a need for development of a tool for automatic analysis of radiographic images. This tool computes high-opacity abnormalities in lungs and relates to COVID-19 infection. The use of X-ray and CT-scan images are in debate; however, when these are combined with reverse-transcription polymerase chain reaction (RT-PCR) pathological test, it resulted in accurate diagnosis. CT

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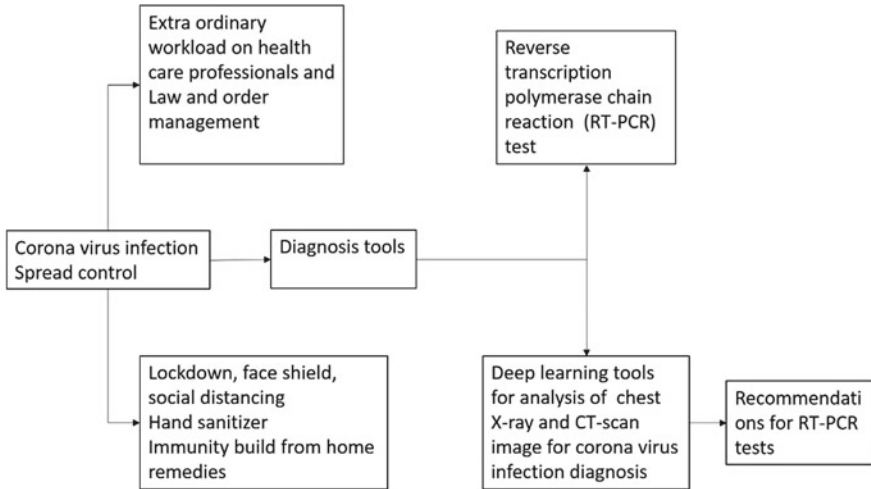


Fig. 1 Strategies to curb coronavirus infection

images are examined for opacity lesions in posterior and peripheral lungs which indicates COVID-19 infections [3]. X-ray is not a powerful tool in finding COVID-19 symptoms, and there were many cases of missing pulmonary nodules which were found in CT scans [4]. Medical professionals facing the challenges of COVID-19 diagnosis are provided with artificial intelligence support system which accelerates the assessment of coronavirus infections from chest X-ray and CT images [5].

Radiologists can investigate COVID-19 infection with the aid of CT scans and X-ray of the chest. The chest CT image demonstrates significant patterns which helps in COVID-19 infection inferences, and important features are ground glass opacities, crazy paving, vascular dilation, traction bronchiectasis, subpleural bands, and architectural distortion. These patterns report the progression of COVID-19 infection, ground glass opacities (GGO) - presence of this pattern in CT image indicates the early stage of COVID-19 infections, these patterns are multifocal, bilateral, and peripheral located in the inferior lobe of right lung, ii. Crazy paving indicates thickened interlobular and intralobular lines, presence of crazy paving in addition to ground glass opacities represents the later stage of COVID-19 infection, iii. Vascular dilation is widening of the vessels in ground glass area, iv. Traction Bronchiectasis is another finding in the areas of ground glass, v. Subpleural bands and Architectural distortion, in some patients there are architectural distortions in addition to new development of subpleural bands [6].

Chest X-rays are significantly useful in triaging and disease progression investigation although these are less informative as compared with CT scans. The COVID-19 pneumonia patterns help in deciding whether CT imaging is required [7]. Chest radiograph images (CXR) in the poster anterior views (PA) are useful in diagnosis of an acute and chronic infection in lungs. The X-rays are examined for lung opacities

which are white vague areas in the dark regions of lungs and lung opacities in X-ray of COVID-19 positive has high contrast regions as compared to the pneumonia X-ray.

The computer-aided diagnostic tools which are designed using deep convolutional neural network models have been useful in pneumonia infection investigation from chest X-ray and CT scan images. In some cases, they have outperformed expert opinions. Therefore, deep learning research community is continuously exploring the feasibility of deep learning paradigm for COVID-19 diagnosis. This paper presents a comprehensive survey on deep convolutional neural network models for corona virus infection diagnosis.

The survey presented in this paper gives an insight into suitability of pre-trained models such as SqueezeNet, VGG-16, VGG-19, GoogleNet, ResNet50, and DarkNet, etc., through transfer learning. The contributions of this work include identification of best pre-trained models, augmentation techniques for COVID-19 positive dataset, enumerates a list of possible dataset with necessary description that are used in research work on analysis COVID-19 chest X-ray and CT-scan images using deep convolutional neural networks.

The paper is organized into different sections, and Sect. 2 gives a brief survey on COVID-19 investigation methods using chest X-ray. Section 3 presents survey on COVID-19 pneumonia detection using CT-scan images. Section 4 gives survey on COVID-19 database, and Sect. 5 presents augmentation techniques, and Sect. 6 discusses on possible research directions for COVID-19 diagnosis using deep convolutional neural network, and Sect. 7 provides conclusion.

2 COVID-19 Infection Diagnosis Using Chest X-Ray Images

The chest X-rays allow quick triaging, X-ray equipment is available in all health care centers, X-rays will be taken in isolated room so there is a low possibility of COVID-19 transmission. The models utilize the salient information content using X-ray images.

Deep learning is a paradigm for automatic feature extraction, and convolutional neural networks are used for feature extraction and classification in various medical applications. In convolutional neural networks, earlier layers extract more primitive features whereas middle layers and end layers extract features that are more specific to image dataset. Therefore, by utilizing the knowledge of state-of-the-art pre-trained models, a novel problem is being solved [8]. Transfer learning is a technique, wherein the feature extracted by a CNN from large image dataset is utilized to solve new problem which needs analysis of altogether a new image dataset, which is small [9]. Deep learning models have limitations to learn features from small dataset from the scratch.

The investigation on COVID-19 infection analysis in [10] is carried out using chest X-ray using deep learning model. The results yielded by the model were utilized in reverse-transcription polymerase chain reaction (RT-PCR) test recommendations. The COVIDx dataset which comprises of 13,975 number of X-rays pertaining to 13,870 patients is used in this work. The database with large number of COVID-19 positive samples is created by combing the images from five open source benchmark COVID-19 databases. A novel convolutional neural network model known as COVID-Net was developed for classification of X-rays as COVID-19 positive cases, COVID -19 negative case and no infection. The authors aimed at building a robust model, and therefore, the model was trained in two stages. In first stage, the model was trained on ImageNet which contains millions of non-medical images, and then in the second stage, it was trained on COVIDx dataset. The model training is carried with hyperparameters: 22 epochs, batch size of 64, and $2e-4$ learning rate, augmentation is applied through intensity shift, translation, zoom, horizontal shift, and rotation. The re-balancing strategy is applied to balance the distribution of dataset. The model is built using Keras libraries with TensorFlow as background [10].

Researchers of [11] have developed a model for classification of X-ray images into COVID-19 positive and COVID-19 negative cases based on inception residual recurrent convolutional neural network (IRRCNN) which is pre-trained on pneumonia dataset. Another model based on NABLA-3 network was developed for segmentation of infected regions from X-ray and CT images. Then IRRCNN model is trained to classify these segmented image patches as COVID-19 infection and normal using strategic transfer-learning technique. Authors claim that the results are encouraging and to get better confidence in the models, they need to be evaluated on large dataset [11].

Authors in [12] have explored the suitability of pre-trained CNNs such as ResNet50, ResNet18, DenseNet-120, and SqueezeNet to draw corona virus infection inferences using chest X-ray images by applying transfer-learning techniques. The models were tuned to classify COVID-19 dataset by unfreezing the last layer of convolutional neural networks, and for earlier layers, pre-trained model weights are utilized. The models are evaluated on publicly available chest COVID-X-ray-5 k dataset comprising 5000 X-rays corresponding COVID-19 positive cases as identified by a radiologist. To improve the performance of these models, COVID-19 positive X-ray images were augmented during training of the model by applying flipping, adding small distortion, oversampling, and rotation operations.

A set of pre-trained models such as MobileNet V2, VGG-16, VGG-19, Inception-ResNet V2, Xception, DenseNet201, ResNet52 V2, Inception V3, and NASLetLarge are explored in [13] using transfer-learning for diagnosis of COVID-19 infections from X-ray. This work uses X-ray images from Dr. Joseph Cohen's COVID-19 dataset. The dataset is augmented on fly during model training using augmentation techniques: rotation, flip, shearing, zooming, cropping, and adding small random noise. The results show that VGG-16 and VGG-19 are superior as compared with models in discussed in this work.

Work in [14] reports the investigations on pre-trained convolutional neural networks: MobileNet v2, VGG-16, Inception, Inception ResNet v2, Xception, for

prediction of COVID-19 infection using transfer-learning. These models are trained on COVID-19 infected X-rays. Transfer learning helps in exploiting the power of pre-trained models when the dataset pertaining to new application is small. The X-ray dataset is collected from medical database which comprises of two sets. First, 1427 number of total X-ray images in which 224 images COVID-19 affected, 700 images falling in bacterial pneumonia, and 504 number of normal images. Second, a dataset comprising 224 number of images representing COVID-19 disease, 714 images of viral and bacterial pneumonia, and 504 images depicting good health conditions. The results show that VGG-16 and MobileNet v2 gave better results.

The research work in [15] explores a novel deep learning model known as DarkNet-19 for COVID-19 pneumonia diagnosis using chest X-ray images. The architecture of this model is designed by considering the architecture trend of DarkNet model as a reference. The model presented in this work follows the trend of convolutional layers from DarkNet, however, with reduced number of filters and convolutional layers as compared to the original DarkNet model. The researchers in this work present their findings stating that to analyze COVID-19 infection, and it is important that the model learns every minute detail from the image and just by designing very deep neural network model like ResNets and ResNext models may not help. The DarkNet-19 model is designed with 17 convolutional layers, batch normalization layer, and LeakyRelu layer. The model is evaluated on Joseph Cohen's dataset, and model gave an accuracy of 98.08%. Authors claim that DarkNet model offers highest classification accuracy as compared to many existing deep learning models.

The investigation presented in [16] design models based on the architectural trend of deep convolutional neural networks such as ResNet50, Inception V3, Inception-ResNetV2 models for classification COVID-19 pneumonia infection. This work uses a popular Joseph Cohen's X-ray repository. The COVID-19 datasets that are publicly available to carry out research are small, and on the contrary to exploit the power of deep convolutional neural networks, large dataset is needed. Therefore, in this work, state-of-the-art pre-trained models which have been trained on ImageNet database are utilized for prediction of COVID-19 infection using transfer-learning techniques. The models are trained in Google collaborative environment, and the parameters include random weight initialization and Adam optimizer. The results show that model based on ResNet50 gave best performance with accuracy of 98%; however, Inception-ResNetV2 gave poor accuracy of 84%.

Most of the publicly available COVID-19 positive datasets are small, investigation in [17] addresses the model overfit issue of deep neural network models when they are trained on a small dataset manifest generalization tendency. This work presents a deep convolutional neural network model known as generative adversarial network (GAN) to generate additional numbers of X-rays on contrast to data augmentation techniques. The research outcome indicates that for classification of COVID-19 pneumonia, a very deep convolutional neural network is not beneficial rather a scheme for detecting salient information from chest X-ray of COVID-19 is needed. The pre-trained models; AlexNet, GoogleNet, and ResNet18 comprise of comparatively a smaller number of layers. Therefore, in this research, these pre-trained models

are used for analysis of COVID-19 dataset using transfer-learning techniques. The models are evaluated on COVID-19 dataset. The performance achieved by AlexNet and GoogleNet is 80.6% and 99.9% of accuracy, respectively. The results indicate that the GoogleNet has yielded highest accuracy. This has an added advantage of reduction in time and memory complexity and suitable for real time analysis.

The work in [18] also explores the usefulness of X-rays in COVID-19 infection detection. The dataset comprising of 122 COVID-19 cases collected from the GitHub. The pre-trained VGG-16 model is adopted for X-ray analysis due to small dataset and therefore applied transfer learning. The last layer is substituted by a fully connected network with 64 neurons, and global average pooling is used for subsampling instead of max pooling. Training is carried out with RMSprop loss function. The model achieved an accuracy of 96.1% with 100% accuracy for COVID-19 classification.

3 COVID-19 Infection Diagnosis Using Chest CT-Scan Images

A large number of pre-trained models with transfer learning are evaluated for classification coronavirus infections, which include SqueezeNet, GoogLeNet, Inception-v3, DenseNet-201, MobileNet-v2, ResNet-18, ResNet-50, ResNet-101, Xception, Inception, ResNet-v2, ShuffleNet, NasNet-Mobile, NasNet-Large, AlexNet, and VGG-16.

The models were trained and evaluated on COVID-19 CT scans which are publicly available [19]. The outcome of this research indicates that there is no need for segmentation of region of interest in CT images and models predict from entire chest CT image. Further, results also indicate that these models gave better results without image augmentation on contrary with augmented image dataset in general [20].

The research investigation in [21] comes out with a deep neural network model for corona virus infection progression analysis. A model known as COVID-19Net is implemented whose architecture is designed by following the architectural trend of DenseNet. This work utilizes a database of 5372 number of CT images in which 4016 CT images are used for training pre-trained deep learning model. The model COVID-19Net is trained on the image patches that corresponds infectious areas in chest CT-scan images. These patches are automatically segmented using pre-trained DenseNet121-FPN mode using transfer-learning techniques. COVID-19Net architecture includes multiple convolutional layers followed by batch normalization and ReLu activation layers, and feature reduction in the last convolutional layer is carried out using global average pooling method. COVID-19Net model performance as indicated by AUC and achieved $AUC = 0.87$ for COVID-19 infection and $AUC = 0.86$ for viral infection. The results of COVID-19 infection classification also showed concurrency with the opinion of radiologist.

In this investigation, a deep learning model is developed by consulting doctors for the recommendation for chest traverse- section CT scans for COVID-19 diagnosis.

The pathological RT-PCR requires longer time for findings of COVID-19 infection analysis. Therefore, doctors expressed that there is a need for AI system which assists in COVID-19 infection detection. The methodology adopted in the development of deep learning model is, traverse-section CT images are preprocessed, and then a 3D CNN is used for segmentation of multiple images cubes which are then classified as infectious and non-infectious. In this work, VNET-IR-RPN deep learning model, a variant of VNET pre-trained model which was used in tuberculosis detection in earlier work is utilized for segmentation. Then, the Bayesian function is used for computation of total score from individual classification results. The model was evaluated on a COVID-19 CT-scan dataset collected from an affiliated hospital in Wuhan city. As the performance of deep learning models demand large dataset, researchers have enlarged the original COVID-19 positive cases dataset by applying image augmentation techniques such as random clipping, left translation and right translation and flipping and mirroring operations [22].

The model detects COVID-19 pneumonia from CT scans by observing the patterns such as crazy paving, ground glass opacities, architectural distortion, and multifocal organizing pneumonia [23]. The AI-based deep learning models are proven to be better than an expert radiologist [24]. A deep learning model which is designed with U-Net architecture as a reference is developed for segmentation of infected area in CT images and inception model as encoder [25]. The COVID-19 CT dataset is collected from Indian Hospital which contains 275 CT scans of COVID-19 patients and total 5212 number of CT images. The model gave 0.964 sensitivity and 0.884 specificity.

A set of pre-trained models modified with transfer learning are used for classification of chest CT scans as corona virus infection and normal cases. The models under consideration were ResNet18, ResNet50, ResNet101, and SqueezeNet. In this work, limited dataset issue was addressed by image augmentation using wavelets followed by conventional augmentation techniques such as rotation, translation, and shear operations. The results showed that ResNet18 have achieved highest testing accuracy of 99.4%. Further, the abnormality in CT scan images are visualized using feature map. Other contributions in this work is a brief survey on COVID-19 diagnosis using X-ray, and CT scans is presented [26].

In this work, a combined model using on recurrent neural network (RNN), and CNN known as ProgNet model is presented for prognosis of COVID-19 pneumonia from a multi-temporal chest X-rays. Time-series analysis is carried out using this model. The RNN model is designed for analysis of chest X-ray radiology time series, and CNN model is for classification of X-ray with COVID-19 and non_COVID-19 infection. The classifier is implemented using pre-trained ResNet50 and LSTM models. This combined model gave an accuracy of 92% for prognosis of X-ray with COVID-19 infection [27].

Three different models are implemented in [28] for classification of corona virus infection, and their performances were compared. The first model is the base model, a convolutional neural network implemented from scratch with five convolutional layers and ReLu function, each layer with 32 filters with 3×3 as kernel size. The base model does use pooling layers and batch normalization layers. The second

model is derived from pre-trained models ResNet50 and DenseNet121 which are fine-tuned using transfer learning. The third model known as COVID-CXNet is implemented using CheXNet which is pre-trained on largest pneumonia and hernia dataset. All these three models were trained on a common COVID-19 dataset. This dataset includes 738 number of chest X-rays diagnosed as COVID-19 positive from RT-PCR tests are collected from various hospitals. The interpretation of these deep learning models is visualized by using gradient weighted class activation mapping (Grad_CAM) and Local Interpretable Model-Agnostic Explanations (LIME) techniques. The performance of these three models are compared, and it is reported that COVID-CXNet gave highest F1 score of 0.96, and base model gave 0.94 [28].

A set of pre-trained convolutional neural network model tweaked for COVID - 19 dataset using transfer learning is used for feature extraction and support vector machine for classification. Pre-trained models VGG-16, GoogleNet, and ResNet50 were used for feature extraction, and features extracted from these models are fused. In this work, total of 3000 image patches of size 16×16 and 32×32 with different gray levels are taken from CT scan images for COVID-19 diagnosis. These patches are labeled as COVID-19 and non-COVI-19 cases. The redundancy in the features set is reduced using t-test which also reduces the memory complexity. These features are classified into COVID-19 infection and normal using SVM classifier. This model outperforms with an accuracy of 95.60% as compared to the results obtained by the individual pre-trained models [29].

4 Benchmark Databases for COVID-19 Diagnosis Using Deep Learning Models

Table 1 is the comprehensive list of databases of X-ray and CT-scan images that are used for COVID-19 diagnosis using deep learning models. This table gives the details about which databases are selected by various researchers to generate a database to incorporate large amount of sample for normal, pneumonia, and COVID-19 pneumonia. These databases contain X-ray and CT-scan images.

The deep learning models give dependable outcomes when they are subjected to large dataset and existence of individual small COVID-19 datasets pose a question on reliability of prediction accuracy of these models. Therefore, all these databases need to be combined to create a large database which helps in tuning-up model performance. Figure 2 shows sample COVID-19 X-ray images from Dr. Joseph Cohen's dataset which are annotated expert radiologist, this is a popular database and widely used in academic research.

Table 1 Benchmark databases for COVID pneumonia infection diagnosis

S. No	Authors	Dataset name	Dataset description
1	Mohammad Rahimzadeha, Abolfazl Attarb [30] [2020]	Covid chest X-ray dataset	This contains 180 number of X-rays from COVID-19 positive cases, 42 for pneumonia
		Rсна pneumonia detection challenge	This contains 6012 number of pneumonia infection X-rays and 8852 number of X-rays of normal persons
2	Enzo Tartaglione, Carlo Alberto Barbano, Marco Calandri, Claudio Berzovini and Marco Grangetto [31] [2020]	COVID-Chest X-ray	It comprises of total 287 CXR and CT images with COVID-19 and other types of pneumonia infections Out of 137 CXRs, 108 COVID-19 positives and 29 COVID negatives
		CORDA: Gathered from website and publications	It contains 447 chest X-rays from 386 patients, 150 samples COVID-19 negatives and 297 positives
		Montgomery County X-ray Set	This dataset contains 138 X-ray images are collected under tuberculosis control program 80 images are from normal patients and 58 are from abnormal patients
		Shenzhen Hospital X-ray Set	This database contains total 662 X-rays, 326 X-rays of healthy patients, and 336 X-rays of abnormal patients
		Chest X-ray	This dataset comprises of 1583 normal patients, 2780 affected by bacterial pneumonia, 1493 affected by viral pneumonia
		RSNA	This dataset comprises of total 20,672 normal chest X-rays and 6012 X-rays of pneumonia case
3	Gianluca Maguolo, Loris Nanni [32] [2020]	NIH dataset/Chest x-ray 8 database	This database comprises of 108,948 X-rays taken from 32,717 patients, and these X-rays are classified into eight categories of infections
		CHE dataset	This dataset contains 224,316 number of X-rays acquired from 65,240 number of patients which are categorized into 14 classes
		KAG dataset	There are 5863 pediatric images
		COV dataset	There are 144 frontal x-ray of corona virus positive patients

(continued)

Table 1 (continued)

S. No	Authors	Dataset name	Dataset description
4	Mohammad Rahimzadeh, Abolfazl Attar, Seyed Mohammad Sakhaei [33] [2020]	COVID-CTSet	This dataset comprises of total 63,849 CT images from 377 patients. There are 15,587 images of 95 number of corona virus patients, and 48,260 CT images of 282 healthy persons
5	Linda Wang, Zhong Qiu Lin and Alexander Wong [10] [2020]	COVIDx dataset	COVIDx is a benchmark dataset with highest COVID positive cases. It contains of a total number of 13,975 CXR images from 13,870 patients This database combines image dataset from five different databases The images of COVID-19 cases are taken from three databases. These include databases: ActualMed COVID-19 Chest X-ray dataset initiative, COVID-image data collection and chest X-ray dataset initiative Dataset for usual pneumonia cases are taken from RSNA dataset and COVID-19 radiography database
6	Ali Narin, Ceren Kaya, Ziyne Pamuk [16] [2020]	Dr. Joseph Cohen dataset	This database contains Chest X-ray and CT-images from the patients suffering from acute respiratory distress syndrome (ARDS), COVID-19, Middle East respiratory syndrome (MERS), pneumonia, severe acute respiratory syndrome (SARS). It contains 50 corona virus positive patients and 50 normal chest X-ray Chest X-ray images Kaggle database
7	Asmaa Abbas · Mohammed M. Abdelsamea · Mohamed Medhat Gaber [34] [2020]	JSRT dataset and Dr. Joseph Cohen’s chest X-ray image dataset	It comprises of 80 chest X-rays of normal cases in Japanese Society of Radiological Technology Dr. Joseph Cohen’s dataset then contained 105 total images with 11 images with COVID-19 and SARS
8	Umut Ozkaya, Saban Ozturk, Mucahid Barstugan [35] [2020]	Societa Italiana di Radiologia Medica e Interventistica	Total 53 CT images from COVID_19 positive patients are taken from Societa Italiana di Radiologia Medica e Interventistica to create a database of CT image patches. In this work generates two sets of data Set-1 comprises of 16 × 16 size patches, 3000—COVID-19 patches and 3000—normal images Set 2 comprises of 32 × 32 size patches, again 3000 number of patches from COVID-19 positive images and 3000-normal images

(continued)

Table 1 (continued)

S. No	Authors	Dataset name	Dataset description
9	Md Zahangir Alom, Shamima Nasrin, M M Shaifur Rahman, Mst, Tarek M. Taha, and Vijayan K. Asari [36] [2020]	Dr. Joseph Cohen's dataset	Dr. Cohen's dataset is used for collecting COVID-19 positive dataset [37] Kaggle repository chest X-ray pneumonia images, which contains, the total number of 5216 images with 1341 normal and 3875 pneumonia infected images Kaggle repository lung segmentation image chest dataset with masks A total of 420 CT images collected which contains 247 normal and 178 images are COVID-19 affected
10	S. Tabika, A. Gómez-Ríos, J.L. Martín-Rodríguez, I. Sevillano-García, M. Rey-Areac, D. Chartea, E. Guiradod, J.L. Suárez, J. Luengo, M.A. Valero-González, P. García-Villanovab, E. Olmedo-Sánchez, F. Herrera [38] [2020]	Blend of 6 databases	COVID-19 image data collection is used for COVID-19 dataset. This dataset contains 76 COVID positive cases and 26 COVID-19 negative cases The database of non-COVID-19 is generated from five databases, they are SNA Pneumonia CXR challenge dataset, COVID-19 Chest X-ray dataset initiative, Chest X-ray8, MIMIC-CXR dataset, and PadChest dataset
11	Rohit Lokwani, Aniruddha Pant, Ashrika Gaikwad, Viraj Kulkarni, Amit Kharat [39] [2020]	Indian Hospital database	This work uses CT scan images from COVID-19-positive and non-COVID data from GitHub and consolidation and healthy CT scans from Indian hospital. This data contains 275 CT scan COVID-19-positive findings from 143 patients. These images are validated from ground truth results obtained from RT-PCR tests
12	Chiou-Jye Huang, Yung-Hsiang Chen, Ping-Huan Kuo, Yuxuan and Ma [40] [2020]	Surging News Network and World Health Organization (WHO)	Database is created from the data collected from Hubei Province, Zhejiang, and Guangdong Province cities
13	Aayush Jaiswala, Neha Gianchandania, Dilbag Singha, Vijay Kumarb and Manjit Kaurc [41] [2020]	SARS-CoV-2 CT scan dataset	The dataset comprises of a total of 2492 CT-images. 1230 are negative for SARS-CoV-2 infection, and 1262 are positive for SARS-CoV-2 infection

(continued)

Table 1 (continued)

S. No	Authors	Dataset name	Dataset description
14	Sakshi Ahuja, B.K.Panigrahi, Nilanjan Dey, Venkatesan Rajinikanth, Tapan Gandhi [42] [2020]	Covid-ct-dataset UCSD-AI4H/COVID-CT https://www.medrxiv.org/ https://www.biorxiv.org/	This work makes collection 349 CT scans COVID-19 positive across 216 patients and 397 CT images from non-COVID patients by combining dataset from of COVID-ct-dataset, images from medrxiv.org and biorxiv.org websites

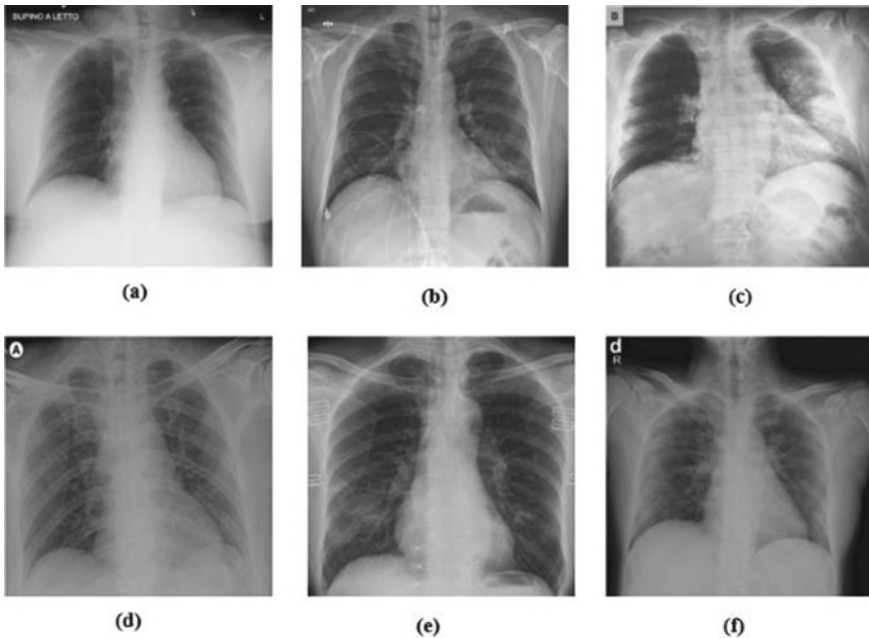


Fig. 2 Dr. Joseph Cohen’s dataset, **a** cardio-visual shadow, **b** increased left basilar opacity indicating development of infection, **c** consolidation and progressive infiltrate, **d** ground glass opacities in lower lobes and small consolidation in upper lobe, **e** right infrahililar opacities demonstrating infection, and **f** progression of bilateral perihilar infiltration with ill-defined patchy opacities [37]

5 Image Augmentation for COVID-19 X-Ray and CT-Scan Image Dataset

Image augmentation techniques are needed to enlarge the dataset and thus addressing the issue of imbalanced dataset. The augmentation enhances inter-class variance within training and testing dataset and, therefore, reduces model generalization error [43].

The COVID-19 X-ray images are augmented by mirroring the X-ray image, and then multiple images are derived by applying various operations on original and mirrored image. These operations include, addition of Gaussian noise, shearing images with affine transform, decreasing, and increasing the brightness of images [44]. Dataset balancing is done through image augmentation on X-rays in normal, viral pneumonia, and corona virus X-ray image datasets. Augmentation on normal and pneumonia dataset is carried out once, whereas six times on COVID-19 dataset. Rotation by 5, 10 and 15 both in clockwise and anticlockwise directions is applied to normal, pneumonia, and COVID-19 positive images. Translation by -5% and $+5\%$ is applied to only normal and pneumonia images [45]. The work presented in [46] uses images augmentation techniques: flip vertical, horizontal, and vertical plus horizontal, rotation by $-90, 60, 90$ and 150° , translation by 10 and 50, brightness by 0.5 and 1.5, flip vertical, horizontal and vertical plus horizontal with change in brightness between 0.5 and 1.5. Experimental results showed improved model accuracy.

In the paper [47], the researchers augment the COVID-19 X-ray dataset on fly during model training with parameters such as rotation, shearing, and zooming by 20%. Image augmentation is applied to counter the COVID-19 positive dataset. During training, each image is randomly picked, and augmentation is done by performing horizontal flip, zooming at the center, rotation, and translation operations, and authors have reported that this has increased number of positive predictions for truly positive cases [48]. The work in [49] focuses on the preprocessing steps when COVID-19 X images from different databases need to be combined into one large database, however, to enlarge the database, further image augmentation techniques are applied by adjusting contrast, saturation, flip left right, flip up down, flip up down left right, and rotations.

Generative adversarial network (GAN) [50] is combined with variational autoencoder to generate additional fine grain X-rays from COVID-19 database. The resulting image set was validated by doctors rating them between 0 and 5. Then based on the average from the rating by 5 doctors, X-rays with score lower than 4.5 are eliminated. Finally, image augmentation is applied on the resulting image dataset [51]. The investigation in [52] states that GAN is not suitable for generation of high-resolution images and, therefore, explored a variant of GAN known as Auxiliary classifier GAN(AC-GAN) for COVID-19 X-ray dataset augmentation through synthetic image generation. The AC-GAN takes as an input latent vector noise and class label as inputs and generates an X-ray image that falls in the category of COVID-19 positive case. The performance convolutional neural network which designed in this work for COVID-19 X-ray image classification is evaluated on original dataset and augmented dataset, and they observe there is 10% increase in the model accuracy on augmented dataset.

To generate a balanced CT scan image dataset for COVID-19 analysis, a technique is presented which combines conventional augmentation approach with synthetic CT image generation to mimic COVID-19 positive cases. In this work, synthetic chest CT images are generated using conditional generative adversarial network (CGAN). The final database included original COVID-19 positive CT images, augmented images,

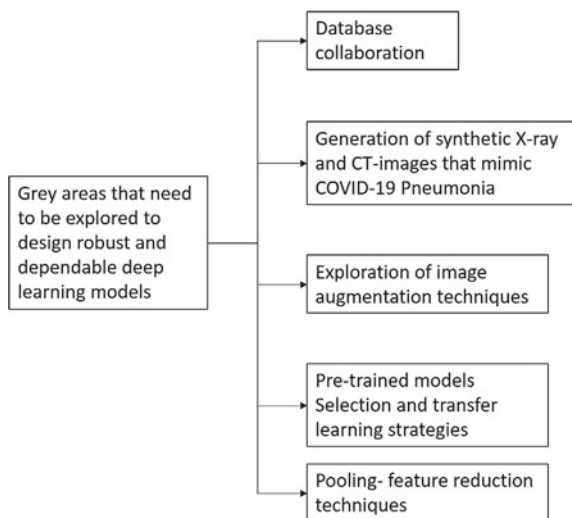
and images generated by CGAN. With these techniques, the original validation set for COVID-19 positive and non-COVID-19 is increased from 60 to 870 and 58 to 846, respectively. The conventional augmentation techniques include operations: rotate 45 degrees vertical flip, rotate by 45 degrees, vertical flip, and horizontal flip operations. The pre-trained models AlexNet, VGGNet16, VGGNet19, and ResNet50 are explored for COVID-19 diagnosis using CT scan images dataset resulting from conventional augmentation and CGAN. AlexNet, VGG-16, and ResNet50 have shown considerable improvement in classification accuracy, and VGGNet19 and GoogleNet have shown moderate improvement [53].

Investigations in paper [26] are aimed at exploiting the information extraction capability of wavelets, the CT scan COVID-19 and non-COVID-19 training set images are decomposed up to three levels by applying Haar and Daubechies wavelets, then augmentation techniques such as shear, translation, and rotation are applied on resulting images. The pre-trained models ResNet18, ResNet50, ResNet101, and SqueezeNet are using for COVID-19 diagnosis using these CT images with transfer learning. The test accuracy of 99.4% is achieved by ResNet18 model.

6 Research Directions and Challenges

The survey presented in this work on deep convolutional neural networks which are used for the diagnosis of corona virus lung infection provides an insight into various challenges faced by the researchers. This study also gives directions to carry out further research. The various research challenges are represented in Fig. 3, and they are

Fig. 3 Research directions in COVID-19 pneumonia diagnosis



Deploying COVID-19 positive case X-ray or CT scan image database by collaborating open dataset facilitated by medical organization, GitHub repository, and datasets from Kaggle competitions dataset.

There is an issue in publishing the dataset by health organizations due apprehension of negative impact on the society, and therefore, there is a need for generation of synthetic images and explore credibility of deep learning models in COVID-19 infection diagnosis as these models demand large amount of data. Therefore, there is need for exploration of techniques for generation of synthetic X-ray and CT-images.

The Keras library provides ImageDataGenerator which helps in image augmentation, and therefore, in a similar manner, there is a need to explore deep learning platforms that helps in image augmentation in consultation with radiologist.

The potential of deep learning models can be exploited by designing right architecture for a model so that model shows success in capturing salient information relevant to corona infection from X-ray and CT-images. Therefore, there is need to explore the strategy for fixing the architectural parameters of deep convolutional neural networks. Typical parameters include number of convolutional layers, number of filters in each layer, size of the filters, weight initialization strategies for filters, size of stride, and pooling strategy for dimension reduction. Therefore, there is need to carry out huge experimental research and conclude which parameters are the best.

The performance of convolutional neural networks also depends upon the strategy adopted for feature reduction in pooling layer, survey indicates that global average pooling preferred on contrary with max pooling. Also, some researchers have explored wavelets-based feature reduction techniques. Therefore, there is need to carry out detailed research to explore different types of wavelets to implement pooling layers.

7 Conclusion

In this paper, a critical survey and analysis on various deep learning models used for analysis of COVID-19 infection are presented. This survey gives an insight into the scope for exploiting the knowledge of benchmark pre-trained models for COVID-19 pneumonia infection diagnosis on contrary to building a deep learning model from the scratch, which demands high computational power and rigorous experimentation. Other contributions include recommendations on combining publicly available COVID-19 positive dataset into single large database to counter the problems posed by imbalanced dataset. The work also presents a thorough investigation on suitable augmentation techniques and other synthetic image generation techniques as applicable to COVID-19 X-ray and CT-scan images.

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