97%. MobileNetv2 achieved an accuracy of 95.73% and F1-score of 96%, while ResNet50 achieved an accuracy of 91.54% and F1-score of 91%.

Wang et al.[22] developed an open-source CNN called COVID-Net to detect COVID-19 cases using chest X-ray images. The proposed net can predict the case as one of three classes which are COVID-19 viral infection, non-COVID-19 infection, and normal. Also, an open access benchmark dataset COVIDx was introduced, it contains 13,975 X-ray images collected from 13,870 patients. The COVIDx dataset was generated using five different publicaly available datasets. The accuracy of COVID-Net reached 93.3%.

Panwar et al.[23] developed a deep learning model called nCOVnet for detecting COVID-19 based on X-rays. A dataset of 284 X-ray images was used of which 142 images are normal cases and 142 images are COVID-19 cases. The model achieved an accuracy of 88.1%.

Nigam et al.[24] used transfer learning to utilize 5 pre-trained models which are DenseNet121, NASNet, Xception, VGG16, and EfficientNet to classify Coronavirus suspected cases as normal, COVID-19 positive cases, and other classes. The used dataset contains 16,634 X-ray images, 6000 normal images, 5634 COVID images, and 5000 imges for others. The achieved accuracies were 79.01%, 85.03%, 88.03%, 89.96%, and 93.48% for VGG16, NASNet, Xception, DenseNet121, and EfficientNet respectively.

Chow et al.[25] used transfer learning to utilize 18 CNN models including VGG-19, VGG-16, ShufeNet, SqueezeNet. etc. to classify the cases as normal or COVID-19. The used dataset contains 700 X-ray images (350 normal cases and 350 COVID-19 cases) from both public and private institutes. The highest 4 models are VGG-19, VGG-16, ResNet-101, and SqueezeNet with accuracy ranging from 90.7 to 94.3% and F1-score from 90.8 to 94.3%. The VGG-16 is the highest with an accuracy of 94.3% and F1-score of 94.3%. The majority voting of the 18 models and the highest 4 models achieved an accuracy of 93.0% and 94.0%, respectively.

The proposed framework

In this section, the proposed framework has been explained. First, the used chest X-ray dataset has been described. Then, the developed framework, which includes "pre-processing" phase and the "Classification using CNN models based on transfer learning" phase, has been illustrated. Two different approaches have been used to train pre-trained CNN models using transfer learning. The first approach uses whole chest X-ray images, while the other approach uses lung-segmented images.

Used datasets

In this research, the data obtained from the "COVID-19 Radiography Database" has been used to apply the proposed framework. The database contains thousands of publicly available benchmark X-ray images and corresponding lung masks. The X-ray images are provided in Portable Network Graphics (PNG) format with a resolution of 299 × 299 pixels. The database includes 10,192 Normal cases, 3616 positive COVID-19 cases, 1345 Viral Pneumonia cases, and 6012 Lung Opacity images as shown in Table1. This database was developed by a team from Qatar University, Dhaka University, Bangladesh with cooperators from Malaysia and Pakistan and cooperators of medical doctors[26]. Figure 1 illustrates samples from different classes in the COVID-19 Radiography Database.

Preprocessing

The purpose of the pre-processing phase is to prepare the X-ray images for classification using CNN pre-trained models. In this phase, different pre-processing steps are applied to improve the performance of the classification. The pre-processing steps can be summarized as follows:

Classes	Normal	Positive COVID-19	Viral pneumonia	Lung opacity
Number of cases	10,192	3616	1345	6012

Table 1. COVID-19 radiography database distribution.

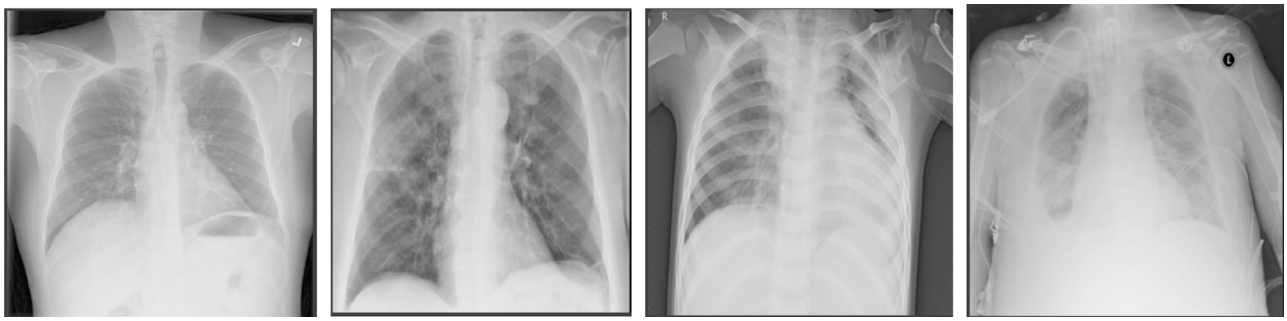

Figure 1. Samples from COVID-19 radiography chest database representing different classes.