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A DEEP LEARNING BASED COVID-19 DETECTION FRAMEWORK

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***Abstract*—The CORONA Virus Disease (COVID-19) is a respiratory disease caused by Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2). Although the RT-PCR is the standard testing method, the use of X-rays can be a beneficial alternative COVID-19 testing method, as they can be used to identify abnormalities in the lungs which are suggestive of COVID-19 and can be used to monitor the disease progression.**

The goal of this paper is to design and implement a GAN enhanced deep learning based COVID-19 detection framework for automatic Covid-19 detection by classifying Chest Radiographs into three classes (Covid-19, pneumonia and Normal). To achieve this, the application of Generative Adversarial Networks and classical data augmentation techniques to a modified VGG-19 convolutional neural network to produce a framework that provides accurate and precise detection of COVID-19 through chest X-rays is proposed. The proposed framework achieved a 91.3% accuracy, 91.3% precision, 90.4% F1 score and 91% recall.

Keywords— Covid-19 detection, Chest X-rays, Deep Learning, GAN, Classical data augmentation, machine learning.

I. INTRODUCTION

The Corona Virus Disease (COVID-19) is a respiratory disease caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) [1].The COVID-19 pandemic begun in the Wuhan area of China in 2019 and has become a significant health concern worldwide. The infection is transmitted mostly via close contact and through respiratory droplets spread when a COVID infected individual coughs or sneezes. The COVID-19 is sometimes referred to as acute pneumonia Candra et al. [2] due to its symptomatic similarity to pneumonia.

Early COVID-19 symptoms often experienced by patients are fever, cough, and fatigue. As the disease progresses, massive alveolar damage and progressive respiratory failure could lead to death [2]. Although the death rate of the disease is simply 2%, the more significant concern is how quickly the virus spreads amongst humans. The COVID-19 is extremely infectious with a high incidence rate of the virus sitting within a range of (1.5 - 3.5). Therefore, early diagnosis is important to curb the spread of the virus, this nonetheless, has proved to be very challenging because the virus can stay inactive in humans for nearly 5 days before showing any symptoms [3].

Presently, the Reverse Transcription Polymerase Chain Reaction (RT-PCR) is the most accurate way of diagnosing COVID-19. Recent innovations of RT-PCR are able to yield results in a 15 minutes, but it is an expensive approach and often unavailable in remote areas.

The rapid spread of covid-19 has led to a limited quantity of available RT-PCR test supplies and an increase in cost of testing. This has caused a reduction in the number of COVID-19 tests carried out, especially in low income countries [4]. The use of X-rays can be a beneficial alternative COVID-19 testing method as they can be used to identify abnormalities in the lungs which are suggestive of COVID-19 and can be used to monitor the disease progression, it is albeit a tedious method.

Therefore, the application of deep learning to the process of detecting COVID-19 via X-rays is being explored. One of the problems encountered in this approach is the insufficient amount of X-ray images available for the development of an accurate and precise deep learning based COVID-19 detection framework.

II. LITERATURE REVIEW

COVID-19 has become a threat to humanity, due to its high infectious rate, it has been declared a pandemic by the World Health Organization (WHO). Without a clear vaccine, early diagnosis seems to be the best means of curbing the spread of the virus. RT-PCR, Rapid antigen test and Chest Imaging are currently used for covid-19 diagnosis.
This section discusses deep learning concepts and data augmentation methods that can improve the process of detecting covid-19 through the use of X-rays. These concepts and methods include-

i. Convolutional Neural Networks
ii. Transfer Learning
iii. Data Augmentation

A. *Convolutional Neural Network (CNN)*

A CNN is a kind of deep learning model used in processing datasets that have a grid like structure, for example- images. The CNN architecture imitates the layered learning of the visual cortex in the brain, which consists of alternating layers of simple and complex cells [5]. This enables the network to adaptively learn features at different levels of abstraction.

CNN architectures are typically composed of three types of layers- convolution, pooling, and fully connected layers. The first two layers (the convolution and pooling layers) which are grouped into modules perform feature extraction, while the fully connected layer converts the extracted features into final output, such as classification. In a standard feed forward network, there may be more than one fully connected layers.

The advantage of CNNs over other classification algorithms is that CNNs learn the best features to represent the objects in the images and have a high generalization capacity, this improves their ability to precisely classify new examples with just a few examples in the training set. In this research, the CNN built in this research performs feature extraction and classification of frontal chest X-rays.

B. Transfer Learning

Rebuilding deep learning models from the beginning, is a time consuming and complex process that requires an abundance of data. This tedious task can easily be mitigated through transfer learning.

Transfer learning aims to move knowledge from a large dataset called as source domain to a smaller dataset identified as the target domain Transfer Learning works by transferring knowledge learned from previous tasks to make the new tasks more efficient.

Due to its ability to reduce model overfitting. Transfer learning using CNN has successfully been applied in several fields [6].

C. Data Augmentation

Data Augmentation is a method used to address the problem of data insufficiency. In data augmentation, several alterations are performed on the available dataset to produce new data. Data Augmentation approaches are usually applied to the training dataset to prevent system overfitting [7].

Data is augmented under the belief that more information will be extracted from the original dataset using numerous augmentation methods. Data augmentation synthetically alters the magnitude of the dataset used for training through data distortion (warping) or data resampling. Data warping makes changes to the original images but the image labels are preserved. This encompasses augmentations like colour change, adversarial training, contrast improvement, geometric alterations and random erasing. Resampling augmentations create artificial instances and include them to the training set or remove instances from large datasets. This includes generative adversarial networks (GANs), Synthetic Minority Oversampling (SMOTE), random oversampling and undersampling. Data augmentation should only be used on the dataset meant for training the system and should not be applied to the validation or testing dataset. In this research, data augmentation techniques are used to improve the class imbalance present in the research dataset.

D. Related Works

The authors in [1] Compared the results of three pre-trained CNN models (ResNet50, InceptionV3 and VGG16) used in classifying Covid-19, bacterial pneumonia, viral pneumonia and normal chest CT images and chest radiographs. The authors carried out random cropping and contrast adjustment as pre-processing methods before implementing a haralick feature extractor. The framework extracts features such as textual and edge based features. The VGG16 CNN model reportedly achieved the best performance.

The authors used open source datasets from GitHub and Kaggle. The authors in [8] proposed a DenseNet framework for predicting COVID-19 using chest images. They implemented pre-processing techniques including image resizing and image normalization to reduce computational complexity while training the model. A DENSENET-121 model with 4 dense blocks and 3 transition layers was implemented in this framework for feature extraction and classification.

The research carried out in [9] entails an implementation of a VGG-19 CNN for textual feature extraction from a set of X-ray medical lung images (which include normal, infected by bacteria, infected by virus including COVID-19) and classification of the X-ray Images. A drop out value of 0.5 was used for regularization of the lung images. The goal of the researchers was to train a deep CNN that can differentiate between the noise and the important features.

Some researchers have designed frameworks that combine different machine learning and deep learning models and techniques in order to improve the performance of the frameworks in detecting COVID-19 from chest X-rays. The authors in [2] Presents a study aimed at determining whether patients examined are infected with the Corona virus by examining the X-rays of the patients using a CNN. The Chest X-rays data are first resized before a CNN was used as a feature extractor. The extracted features further undergo feature selection using either Principal Component Analysis (PCA) or relief method. Support Vector Machine was then used as the classification method.

The authors in [3] Provides a detailed discussion of the methodical challenges of deep-learning-based detection of COVID-19 and their possible solutions. A comparative quantitative analysis of the performance of 315 deep learning models used in detecting COVID-19, Normal, and Pneumonia from x-ray images. The results of the analysis showed that DenseNet201 model combined with a Quadratic SVM classifier achieved the best accuracy, specificity and sensitivity in comparison to the other models tested by the authors. In an attempt to increase the size of the dataset used for research and reduce data imbalance, data from multiple sources can be combined to form a new dataset.

Convolutional Neural Networks require a large number of data to produce good results. As reported in some research papers including [10], the number of available COVID-19 radiographic images available for research is limited. Several approaches have been made by researchers in this regard. The authors in [10] presented a framework for COVID-19 detection that showed the adoption of the use of a Generative Adversarial Network (GAN) by the researchers to generate synthetic chest X-ray (CXR) images. The framework performs binary classification of COVID-19 and Normal chest X-rays. The GAN was applied to both datasets to generate 500 images which are then used to train the CNN. The COVID-GAN framework produced a higher accuracy in comparison to a classification using only CNN which yielded an 85% accuracy.

The main idea in [11] was to collect as much COVID-19 chest X-rays as possible and use GAN to further produce images to help improve the performance of the proposed model in the detection of covid-19. The proposed system performs classification with respect to three case scenarios, the first scenario contains four classes of lung conditions, while the second scenario contains 3 classes and the third scenario contains two classes. The principal class in each scenario is COVID-19. Alexnet, Googlenet, and Restnet18 were selected as the CNN frameworks for this study.The authors concluded that GAN generated images can be advantageous in enhancing the performance of Convolutional Neural Network for COVID-19 detection.

Similar conclusions were drawn by the researchers in [12] and [13]. The researchers in [12] and [13] concluded that GAN generated images can effectively solve the problem of a small sample size and class imbalance.

In [14] a framework that extracts deep features of chest X-rays using ResNet152. The paper aims to classify three classes of Chest X-ray data- COVID-19 and Pneumonia. Synthetic Minority Oversampling Technique (SMOTE) was used to increase the covid-19 and Normal patient dataset. The paper further compares the performance of the Random Forest and XGBoost classifiers. When combined with the proposed data augmentation and feature extraction method, the framework achieves better accuracy than when the machine learning classifiers are implemented individually.

In [15], data is sourced from four public repositories containing posterior anterior (PA) chest X-rays for COVID-19, pneumonia and normal lung conditions.

The aim of the research in [16] was to provide an alternative method for Covid-19 detection via the use of infected patient chest radiographs. Three sets of binary classifications with four classes - COVID-19, normal, viral pneumonia and bacterial pneumonia, was carried out by using k-fold cross validation.

The authors in [17]. Compared the performances of four architectures- Xception, ResNet50, MobileNet, and Inception V3. Keras framework which used pre-trained weights combined with TensorFlow as the backend was used in designing the framework. The networks were trained using Adadelta and Mean Squared Error was selected as the loss function.

In [18] a discriminative fine tuning approach was combined with mixed precision training to develop a flexible and computationally efficient CNN. Each layer of the CNN has a dynamically set learning rate. This technique was implemented to improve rapid model convergence.

A deep feature plus support vector machine (SVM) based methodology is suggested in [19] for detection of coronavirus X-ray images. For classification, SVM was used to replace the softmax layer. The deep features from the fully connected layer of CNN model were extracted and fed to SVM for classification purpose. The methodology consists of three categories of X-ray images, i.e. COVID-19, pneumonia and normal.

III. PROPOSED DESIGN FOR THE DEEP LEARNING BASED COVID-19 DETECTION FRAMEWORK

The Deep Learning Based Covid-19 Detection Framework will be developed using python programming language, keras and tensorflow library. The important stages of the framework are:

i. Data augmentation
ii. Feature extraction and image classification

A. Data Augmentation

Data Augmentation is carried out during training of the proposed deep learning based framework. The goal is to increase the size of the smallest data class and to eventually balance the dataset. A combination of Generative adversarial Network (GAN) and classical data augmentation techniques are used to achieve this. The GAN produces synthetic image data by learning the features of all the images in the smallest data class. This synthetic image is then used to increase the size of the dataset. The dataset generated by the GAN resembles real world data and it is added to the training datasets of the GAN enhanced deep learning based COVID-19 detection framework. The training dataset is a combination of randomly selected data generated by the GAN and the raw data from our original data repository. The training dataset is further skewed, rotated and zoomed before it is used to train the framework. This enables the framework learn more features of the image and improve the classification of the framework. For the design of this framework, the smallest data class is the covid-19 data class. The GAN equation is given by Equation (1).

$$min_G \; max_D \; L(D,G) =$$

$$E_{x\sim ptan(x)}[logD(x)] + E_{y\sim p(y)}[\log(1 - D(G(y)))] \quad \textbf{(1)}$$

B. Feature Extraction and Classification:

The features of the image are then extracted by the convolution and pooling layers of the VGG-19 CNN, the results obtained from these layers are used to classify the image into one of the labels (COVID-19, Pneumonia and Normal). After classification, the result of the classification is displayed using a desktop application.

Figure 1 shows the architecture of the COVID-19 detection framework.

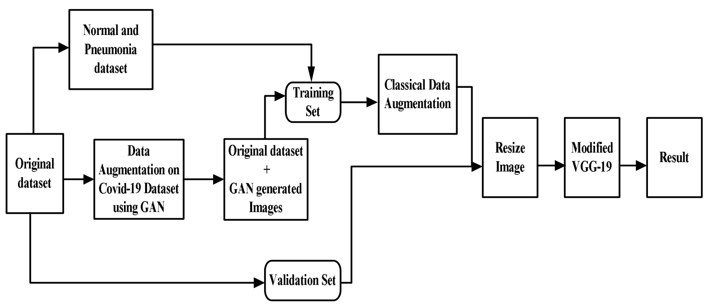

Fig.1: The Architecture of the Framework

C. The Dataset

The dataset acquired from the repository in [20] contains post anterior view X-ray images labelled covid-19, viral pneumonia and normal. 700 covid-19 X-ray images, 1345 viral pneumonia X-ray images and 1341 normal X-ray images were collected from this repository, 80% of these images were used for training the model while 20% of the images were used to test the model. A GAN was used to create synthetic data in a bid to increase the size of the covid-19 training dataset to 1339. A total of 4025 post anterior chest images have been used to carry out this research.

D. GAN Pseudocode

The GAN used in the design of this framework is a trained using Minibatch stochastic gradient [21]. The pseudocode is repeated until the GAN produces images that closely resemble the original images.

1. **for** each iteration during training do:
2. Update the discriminator using stochastic gradient ascent
3. **for** z steps do:
4. Sample the mini-batch of n noise samples y_1 y_2 , ... y_n and mini-batch of n real samples x_1 x_2 ... x_n
5. Update the parameters of the discriminator (D) using stochastic gradient ascent on-

$$\frac{1}{n}\sum_n[\boldsymbol{logD}(\boldsymbol{x_n}) + \mathbf{log}\left(\mathbf{1} - \boldsymbol{D}(\boldsymbol{G}(\boldsymbol{y_n}))\right)] \quad \mathbf{(2)}$$

6. **end**
7. Sample the mini-batch of noise samples y_1 y_2 , ... y_n
8. Update the generator using stochastic gradient ascent on-

$$\frac{1}{n}\sum_n[logD(G(y_n))] \quad \mathbf{(3)}$$

9. **end**

E. . CNN Pseudocode

1. Load GAN enhanced training images (X, Y);
   $\boldsymbol{Where\ Y = \frac{y}{y} \in \{COVID - 19\ , Pneumonia\ and\ Normal\ \}}$
2. **procedure** Find Label (Image Name)
3. **if** $COVID - 19\ \in \boldsymbol{Y}$ **then**
4. **return** 0
5. **if** $Normal\ \in\ \boldsymbol{Y}$ **then**
6. **return** 1
7. **else if** $Pneumonia\ \in \boldsymbol{Y}$ **then**
8. **return** 2
9. **end if**
10. **end procedure**
11. **for** each $\boldsymbol{x}$ in $\boldsymbol{X}$ **do-**

    modified_new1 ($\boldsymbol{x_{\alpha_i}}$) = *filter* ***(x.rescale)***
    modified_new2 ($\boldsymbol{x_{\alpha_{ii}}}$) = *filter* ***(x.shear_range)***
    modified_new3 ($\boldsymbol{x_{\alpha_{iii}}}$) = *filter* ***(x.horizontal flip)***
    modified_new4 ($\boldsymbol{x_{\alpha_{iv}}}$)= *filter* ***(x.zoom_range)***
12. **end procedure**
13. **end for**
14. *Augmented_image* ($\boldsymbol{x_\alpha}$) ={($\boldsymbol{x_{\alpha_i}}$) + ($\boldsymbol{x_{\alpha_{ii}}}$) + ($\boldsymbol{x_{\alpha_{iii}}}$) ($\boldsymbol{x_{\alpha_{iv}}}$)}
15. **Resize** ($\boldsymbol{x_\alpha}$)
16. **return** ($\boldsymbol{x_\alpha}$)
17. Load and reuse the VGG-19 transfer Model **(V)**
18. Load a single Flatten layer and a single fully connected dense layer.
19. **Set** VGG-19-***Cost*** = ***tf .nn. sigmoid_cross_entropy(logits*** = ***pred, labels*** =$\boldsymbol{Y_{train}}$**)**
20. *Set optimizer* = *tf .train.* δ(μ= 0:01)
21. **for** epochs = 1 to 500 **do**
22. **for each** mini-batch $(\boldsymbol{X_i}, \boldsymbol{Y_i}) \in (\boldsymbol{X_{train}}; \boldsymbol{Y_{train}})$ **do:**
23. Adjust the coefficient of $\boldsymbol{V}_{(.)}$ when error rate () is increased after 5 epochs, **then**
24. **Set** $\boldsymbol{\mu = \mu\ \times 0.01}$
    end
    end
25. **for each** ∀ ∈ $\boldsymbol{X_{test}}$ **do**
26. Predict($\boldsymbol{X_{test}}$, $\boldsymbol{Y_{test}}$)
27. **return** the outcome of the VGG-19 model **(V)**
28. **end**

IV. RESULT AND DISCUSSION

The GAN was trained using the following hyper parameters: batch_size=32, buffer_size=50000, batch nominalization momentum= 0.8), number of epochs=500. Several dropout layers are incorporated in the design of the GAN to prevent overfitting of the GAN model.

The convolution layers of the VGG-10 CNN model were frozen and the models weights were imported from Imagenet. A single flatten layer and dense layers with relu and softmax layers are then included to the model. The classifier incorporates an Adam optimizer to adjust the model weights by 0.001. The model is trained for 500 epochs. Classical data augmentation is applied to the COVID-19, Normal and Pneumonia X-ray training images. Some of the data augmentation techniques applied include image rescaling and flipping.

Figure 2 is an image of some COVID-19 images generated by the GAN. The images that were not correctly generated were automatically removed before the generated images were added to the training dataset.

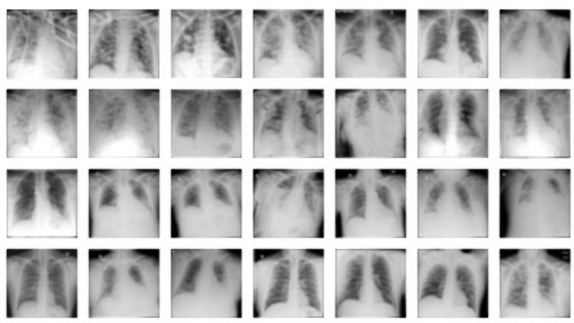

Fig.2: Some COVID-19 images generated by the GAN

Figure 3 shows the percentage of chest X-ray images correctly classified and misclassified by the designed model. **0 represents the COVID-19 class, 1 represents the Normal class and 2 represents the viral-pneumonia class.** The designed deep learning model correctly classified 94% of the covid-19 chest X-rays.

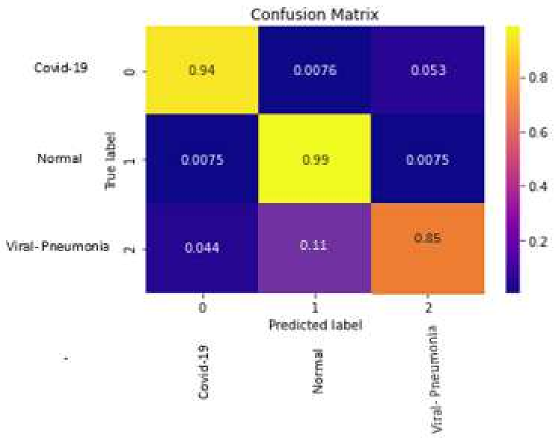

Fig. 3: Confusion matrix of the deep learning framework

Table I shows the comparison between the proposed GAN enhanced deep learning based COVID-19 detection system and other models that have implemented a variant of GAN in their design. From the table, it can be noticed that the proposed model achieves a higher accuracy than the referenced models. The models from the referenced research materials were tested on our dataset.

TABLE I: COMPARISON WITH A REVIEWED MODEL

S/N	MODEL	Accuracy	Precision	F1-Score	Recall
1	Resnet [12]	86.8%	87.6%	86.7%	84.6%
2	Google-Net [12]	85.3%	88.7%	83.5%	85.2%
3	**Designed deep learning model**	**91.30%**	**91.3%**	**90.40%**	**91%**

V. CONCLUSION

The purpose of this framework is to assist radiologists in examining the lung images of the patients and reduce the diagnostic load of the radiologist. In the cause of this research, it was discovered that the inclusion of synthetic images can improve the total performance of a deep learning based Covid-19 detection framework and the ideology behind this framework can be implemented in several medical imaging models. The developed framework can be implemented across several hospitals in low income countries including Nigeria, as the framework provides an inexpensive, accurate and easy approach to detecting the presence of COVID-19 in the lungs of patients.

Some recommended improvements include-pruning of the developed covid-19 detection model in order to improve computational and memory efficiency and enable it run on devices with less computational strength such as mobile devices. Inclusion of other non-invasive methods of determining COVID-19 positive individuals. The framework currently focuses only on the use of chest X-rays to determine COVID-19 positive individuals.

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