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Detecting Covid-19 and Other Lung Diseases with Deep Learning

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***Abstract*— Since December 2019, Covid-19, also known as severe acute respiratory syndrome (SARSCOV-2), has infected about 531 million individuals worldwide causing devastating consequences. Scientists, health professionals, and radiologists have all invested huge amounts of time, effort and resources in developing faster and accurate methods for detecting the virus as it spreads all over the world. The current gold standards for detecting covid-19 such as RT-PCR, POC, Droplet-based digital PCR (dPCR) and Immunoassays are not only expensive for low-income countries but also require substantial human expert knowledge which in turn makes them time-consuming and susceptible to manipulation. The study presented in this paper aims to address these issues by proposing a model to automatically detect COVID-19 in chest X-rays using Deep Learning techniques. Specifically, the model uses convolutional neural networks (CNNs), a deep learning technique, which has been shown to produced very good results when applied to medical image diagnosis problems. Our proposed model will therefore not only provide a cheaper, faster and accurate method of detecting COVID-19 but will also provide an easy to use web and mobile platform for non-experts. While current detection techniques such the RT-PCR are still considered as the most effective, our CNN-based model was also able to produce good results when applied to the COVID-19 radiography dataset. For instance, the model was able to detect COVID-19 from X-ray images with an accuracy rate of 90 percent. Furthermore, the model was also able to automatically detect other respiratory diseases such as viral pneumonia and lung opacity with an accuracy rate of over 90 percent. Given the potential of the automated detection of COVID-19 established in this study, future work will extend this work by incorporating automated search techniques such as genetic algorithms in the fine tuning of the model's parameters in order to obtain an even higher accuracy rate.**

Keywords*— *Covid-19, Convolutional Neural Network, Deep Learning, Automated search and detection.

I. Introduction

Covid-19 or the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), discovered in Wuhan for the first time, in Hubei province of mainland China on the 31st December 2019, has rapidly become a global pandemic[1]. Coronaviruses like 229E, NL63, OC43, and HKU1 infect people and cause mild to moderate upper-respiratory tract diseases such as the common cold[2]. Coronaviruses are common in animals but sometimes these viruses can evolve and infect humans. Two more human coronaviruses are SARS (server acute respiratory syndrome), which first appeared in 2002 and then disappeared in 2004, and MERS (Middle East respiratory syndrome), which first appeared in 2012 and is still in circulation in camels. And SARS-Cov2, a relative of the SARS virus which emerged in December 2019 is also known as COVID-19 (coronavirus disease 2019). According to literature, the backbone of the COVID-19 gnome closely mimics that of the bat coronavirus found after the COVID-19 pandemic began. However, the area of the virus that binds to ACE2 is similar to a new virus identified in pangolins[3].

Testing, tracking, and tracing infected individuals and their contacts as an effective strategy to reduce the virus spread has been emphasized by public health experts worldwide. Most governments all over the world have since participated in the exercise to varying degrees, employing a variety of testing methods.

One of the most popular approach in use for the detection of COVID-19 is the reverse transcription polymerase chain reaction (RT-PCR) test. This test involves the collection of specimens such as nasal, nasopharyngeal or oropharyngeal swabs from patients in order to examine the existence of RNA in SARS-Cov2. However, the clinical sensitivity for SARS-Cov2 detection is relatively low and can produce varying results. Aside from laboratory testing with a PCR thermocycler machine, radiological image processing of the chest, such as computerized tomography (CT) and X-rays, are other methods of detecting and diagnosing COVID-19 in its early stages. CT scans have a high sensitivity for detecting COVID-19, especially in areas where the pandemic is prevalent. The specificity, on the other hand, is low [4]. In the context of emergency disease control, chest CT offers a quick, easy, and effective way to identify suspicious cases early, which may help to contain the epidemic. Used as a screening tool, CT can cover the low sensitivity factor by the RT-PCR [4]. Other well-known methods for detecting COVID-19 include the Droplet digital PCR (ddPCR)[5] and Immunoassays for antibody to virus [6].

While the above-mentioned approaches provide ways of detecting COVID-19, they however also present a few challenges which limit their applicability to poor or low-income countries. For example, RT-PCR tests require PCR equipment which is prohibitively costly for most poor countries. When transportation to a competent laboratory is included, the time it takes to complete the process is also stated in days. In addition, well-trained personnel are required for sample preparation and analysis operations. Furthermore, increasing demand during a pandemic result in a shortage of swabs, personal protective equipment, PCR reagents, and equipment like thermo cyclers and biosafety level-2 cabinets. Droplet digital PCR (ddPCR) tests are currently even more expensive than RT-PCR tests as they require more specialized instruments and consumables. Immunoassays on the hand when used to detect the virus's antibody response during the early stages of infection may generate misleading negative findings. Sensitivity may also be limited when tested in native communities with undiagnosed or mildly ill individuals who may only produce low-titer antibodies.. If there are several such examples, sensitivity may be significantly reduced. Results might also be skewed by preceding COVID-like diseases that muddle the antibody response's specificity. CT scans frequently involve higher radiation doses than more common, traditional x-ray imaging diagnosis procedures, and radiation exposure can have a long-term biological impact on a patient. CT scans, too, require expensive tools and the expertise of a radiologist to operate and analyze the data.

Motivated by the limitations of the current COVID-19 detection techniques coupled with recent advancements in the fields of Artificial Intelligence and machine learning, we propose to develop a model, using deep learning techniques called convolutional neural networks (CNNs), that not only automatically detects COVID-19 in chest X-rays but also detects other respiratory diseases such as viral pneumonia and lung opacity. CNNs have been chosen due to their effectiveness and successful use in extracting useful features from images in various application domains[7],[8],[9],[10]. The developed model was applied to the COVID-19 radiography dataset and the obtained results show an accuracy rate of 90 percent for the detection of COVID-19. The accuracy rate for the detection of viral pneumonia and lung opacity was over 90 percent.

The rest of the paper is organized as follows: section II discusses related literature and works that have applied CNN in the detection of COVID-19. This is then followed by a discussion of our proposed model in section III. Section IV presents and discusses the experimental setup for evaluating the performance of our approach. Section V presents the study's findings as well as future extensions of the work.

RELATED LITERATURE AND WORKS

As previously stated, the Covid-19 pandemic has had an impact on nearly every aspect of our lives. On one side, it has brought death and on the other side presented opportunities that have allowed us to change the way we live. The lack of specialized experts and financial resources to deal with the pandemic in low-income countries has given impetus to research in the development of automated systems based on Artificial Intelligence (AI) techniques. AI is a broad term that refers to the use of a computer to model intelligent behavior with little human intervention [11].

This section briefly discusses these AI techniques which may be useful in overcoming some of the challenges faced by poor countries.

A. *Machine Learning*

Machine learning (ML) can be broadly described as a field of study which focuses on developing computer systems that improve themselves over time [12]. It is one of the fastest growing fields of research and is often considered as the core of artificial intelligence and data science.

In recent years, Machine learning has emerged as the dominant technique for creating practical software for AI applications such as computer vision, speech recognition, natural language processing, robot control, and so on. Many AI system developers now recognize that, for many purposes, training a system by providing it with examples of desired input-output behavior is far more convenient than manually programming it by anticipating the intended response for all potential inputs. ML techniques have tremendously stepped-up the game in various application domains such as medical diagnosis, speech recognition, object detection and recognition, genomics and drug discovery to mention but a few [13].

B. *Deep Learning*

One of the limitations of traditional ML techniques is their inability to process natural data in their raw form without sufficient domain expertise on the part of the programmer. To tackle this problem, Deep Learning (DL) techniques have been developed. DL techniques allow computational models, usually composed of multiple processing layers, to discover intricate structures from raw and very large datasets.

There are two main learning paradigms: supervised and unsupervised learning. Supervised learning is a type of learning that involves learning partners in pre-labeled inputs (vectors). During training, a set of input values and one or more associated output values will serve as targets. The goal of supervised learning is to reduce the model's overall classification error by correctly calculating the training output value.[14]. Unsupervised learning is distinguished by the absence of labels in the training set. The ability of the network to decrease or increase an associated cost function is usually the criterion for success [14]. Most image-based pattern recognition problems rely on supervised learning for classification [14].

C. *Artificial Neural Network*

An ANN is a computational processing system that is heavily inspired by how the brain works. [14]. An artificial neuron is depicted in Figure 1.

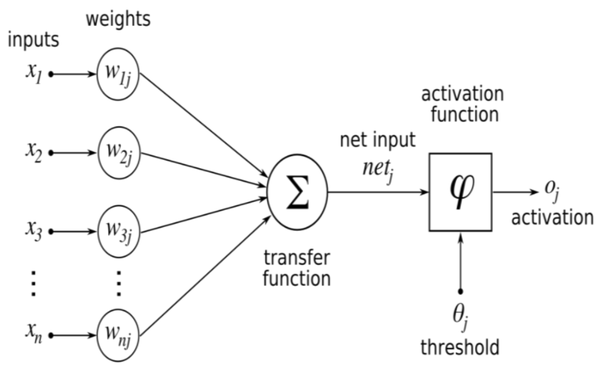

Figure 1 : Artificial Neuron

The neuron's inputs are $X_1 ... x_n$ .Along with the inputs, the neuron receives a bias. The bias value is usually set to 1. The weights are $w_{1j} ... w_{nj}$, a weight is the signal's connection. The signal strength is given by the product of the weight and the input. A neuron has a single output and receives several inputs from various sources. Activation is accomplished via a variety of functions such as the sigmoid, step, linear, ramp, hyperbolic functions.

ANNs are primarily composed of a large number of interconnected neurons that collaborate to collectively learn from input in order to optimize its final output. The architecture of ANN is shown in Figure 2. The ANN architecture is made up of three layers: the Input layer (which receives input values) and the Hidden layer (a set of neurons between input and output layers.) and also the output layer (usually it has one neuron, and its output ranges between 0 and 1).

An ANN with multiple hidden layers is typically considered a 'deep' neural network. The most popular deep learning architectures are convolutional neural networks (CNNs) and recurrent neural networks (RNNs) [15]. CNNs are most widely used in image analysis and will therefore be the preferred architecture in this study.

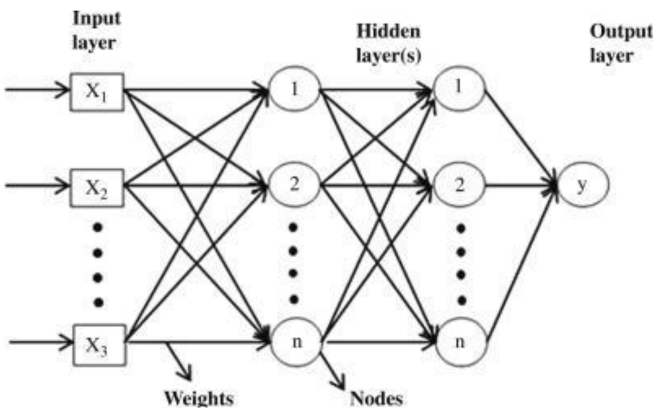

Figure 2 : Artificial Neural Network

D. Convolutional Neural Networks

A CNN is a neural network that specializes in processing data with a grid-like architecture as shown in Figure 3.

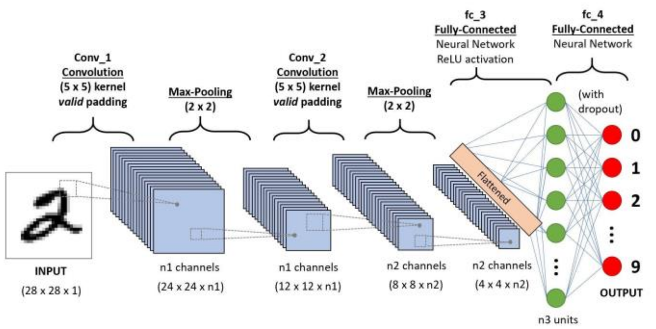

Figure 3: Convolutional neural network (CNN) Architecture

A typical CNN has three layers namely, the convolutional layers, the pooling layers, and the fully-connected layers. These layers are usually are stacked and their basic functionality can be described as follows:

- The input layer – This layer holds the pixel values of the image to be detected.
- In the convolutional layer, the output of neurons connected to specific sections of the input will be determined by calculating the scalar product of their weights and the region connected to the input volume. When used, the rectified linear unit (ReLu) applies a 'elementwise' activation function such as sigmoid to the output of the previous layer's activation.
- The pooling layer performs down sampling along the spatial dimensionality of the input, reducing the number of parameters within that activation even further.
- For classification, the fully-connected layer generates class scores from activations. To improve performance, the ReLu activation function can also be used between layers.

This section provides only a brief discussion on CNNs. A more detailed discussion can be found in[14],[16].

E. Convolutional Neural Networks for COVID Detection

Deep learning techniques like CNNs have been successfully applied in the medical field to detect and classify various problems such as lung segmentation [15], pneumonia [16], arrhythmia [17], neural disease [18], etc.

Similarly, there has been some work done in the area of COVID-19 detection using CNNs. For example, Hemdan et al.[17] The output of 7 different Convolutional neural network based COVID-19 detection models were investigated and compared, namely InceptionResNetV2,ResNetV2, DenseNet201 , InceptionV3, Xception, MobileNetV2 and VGG19. Of the seven models, VGG19 and DenseNet201 and obtained an accuracy of 90 percent. Other works include those done by Wang and sWong [18], Sethy [19], Narin et al.[20], Apostolopoulos and Bessiana [21], Li et al. [22] and many others. Suffice to say that in all these works, the performance of the models in terms of accuracy varied between 88 - 98 percent.

There have been numerous attempts in other parts of the world to detect COVID-19 faster and more accurately, however, Zambia still lags behind with regard to the number of people tested for COVID-19 as the most preferred detection method still involves the use of expensive laboratory testing kits. Our study attempts to bridge this gap by developing a model using the tried and tested CNN to detect not only COVID-19 but viral pneumonia and lung opacity as well. A web and mobile based application were also developed to make it easy for none experts to use the model.

The next section discusses the developed model in more detail.

II. PROPOSED APPROACH

A. CNN Model

As mentioned earlier, our proposed model is based on the CNN. Specifically, the first layer is the resize and scale layer, followed by the data augmentation layer, and then the convolution layer, which contains 32 neurons, (3,3) filter size, and an activation layer as Relu. The fourth layer is a pooling layer, in this instance a MaxPooling layer, which preserves image features while shrinking the image size. The last layers are a flattened layer and a dense hidden layer with a Softmax activation function that normalizes the probability of the classes. The model is shown in Figure 4.

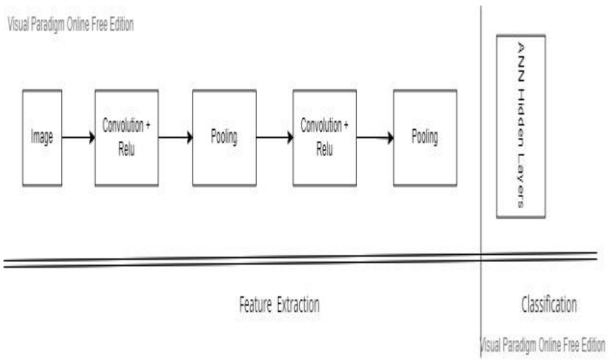

Figure 4 : Proposed CNN model

B. Detection of COVID-19

This process was achieved by taking a picture (using a mobile device or camera) of a chest X-ray image and analyzing it using the trained CNN model. The model was then able to extract the features from the X-ray image and detect the type of the disease if any. A summary of the detection process is depicted in Figure 5.

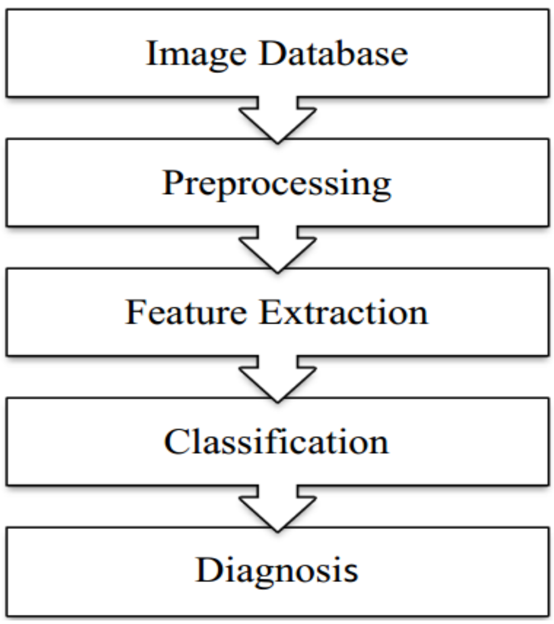

Figure 5 : COVID-19 Detection process

Data Cleaning and Preprocessing stage is the first step in the model training process. It involved cleaning the dataset (which contains 21000 images) and converting it into a tf.dataset (TensorFlow dataset) in order to make it easy to split into training, testing and validation sets. The dataset was split using the ratio 80:10:10 with the training set consisting of 80 percent of the randomly shuffled data. The validation and testing set each contained 10 percent of the remaining data.

The second step in the model training process involved the use of a preprocessing pipeline. In the pipeline, the resize and rescale layer ensured that an image was resized and rescaled if it was not of the correct shape or size. The data augmentation layer enhanced the model by applying different transformations to the image; for example, if a flipped image was fed to the model, it would still classify it correctly.

The third step involved feature extraction using the CNN model described in A. The CNN model was then able to classify the image accordingly and present the results of the diagnosis to the user.

III. EXPERIMENTAL SETUP

A. Experiments

The Adam optimization algorithm was used to optimize hyperparameters used in CNN training steps, the loss function was Sparse Categorical Cross entropy. The network was trained using a batch size of 32 and 50 training epochs while the weights which had the best validation accuracy were retained.

B. Technical Specifications

The proposed model was created in Python using Tensorflow and the Keras wrapper library. The experiments were performed on a Lenovo Intel(R) Core i5-8250U CPU 1.60GHz with 7.43 GB usable RAM and Intel 4000 Graphics.

IV. RESULTS AND DISCUSSION

The model was tested on 4236 images and achieved an accuracy of 90% in classifying Covid-19, Normal, Lung Opacity and Pneumonia X-ray images. The model's classification accuracy was more than 90%.

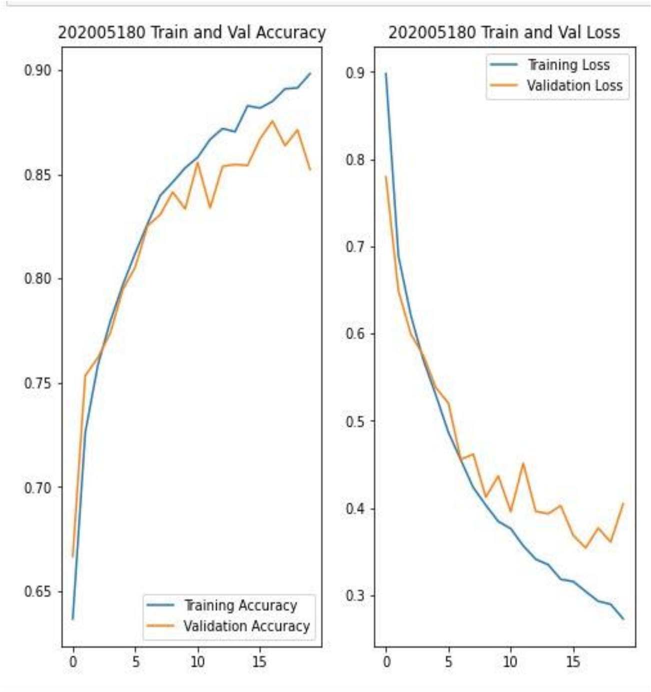

Figure 6: Train and Validation accuracy and loss

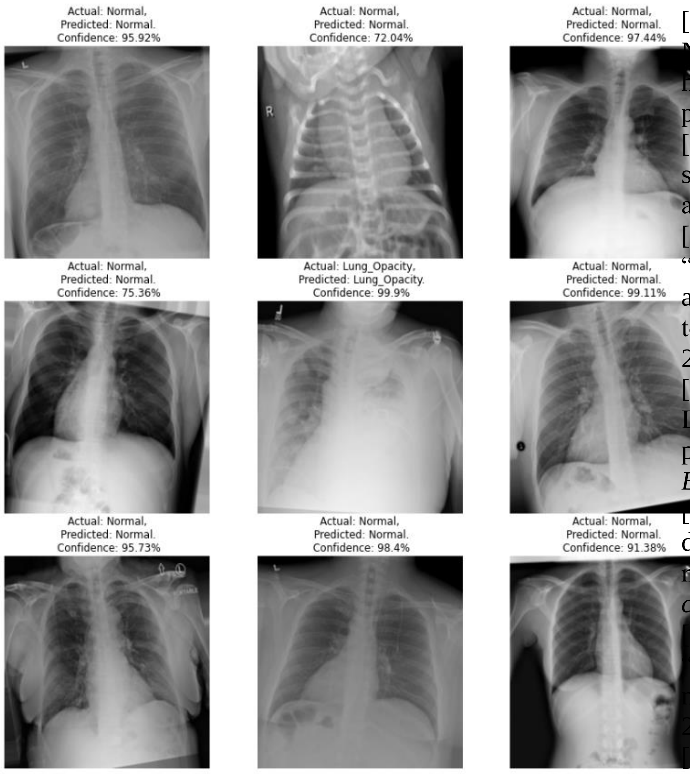

Figure 7 : Predicted class and confidence score

CONCLUSION AND FUTURE WORKS

Given the fact that there is still a need for more research in this field of automated detection of COVID-19 with deep learning, the work presented in this study makes a significant contribution to the field by proposing a novel approach that radiologists and other health professionals can use to detect COVID-19 in its early stages. This proposed model may also serve as a supplement to the RT-PCR machines in identifying COVID-19. Future works may include the following:

- Improving the model's accuracy and produce more accurate predictions. Since the COVID-19 Radiography Dataset is still developing, adding more COVID-19 images to the dataset will help the performance as more features will be extracted.
- To add extra functionality to the React.js and React Native applications, such as login authentication (using AWS (Amazon web service), firebase, or Node.js).
- To deploy the applications across several platforms, including Android (Play Store), iOS (Apple Store), and Web.

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