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# COVID - 19 Automated Detection using Convolutional Neural Networks and Generative Adversarial Networks

A thesis submitted

by

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in partial fulfillment of the requirements for the degree of

Master of Science in Computing in Big Data Analytics and Artificial Intelligence

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Submitted to Quality and Qualifications Ireland (QQI)

Dearbhú Cáilíochta agus Cáilíochtaí Éireann

November 2022

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# Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Science in Computing in . . ., is entirely my own work and has not been taken from the work of others except and to the extent that such work has been cited and acknowledged within the text of my own work. No portion of the work contained in this thesis has been submitted in support of an application for another degree or qualification to this or any other institution. I understand that it is my responsibility to ensure that I have adhered to LYIT's rules and regulations.

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Date: \_\_\_\_\_ Thursday 10<sup>th</sup> November, 2022

# Acknowledgements

I would first of all like to thank my supervisor during this project Dr. Paul Greaney, he was a fantastic help throughout the course of writing this thesis and this work could not have been completed without his input and help.

I would also like to thank the lecturers who taught me so much during my postgraduate course, both Doctors Karla Muñoz-Esqueival and Shagufta Henna provided a fantastic introduction into many areas of Artificial Intelligence and the knowledge they imparted has helped me a lot throughout the course of conducting this research.

I would also like to thank Andrew Ng, his deep learning courses provided a great foundation into the realm of deep learning and Artificial Intelligence.

# Acronyms

- AI - Artificial Intelligence
- ANN - Artificial Neural Network
- CNN - Convolutional Neural Network
- GAN - Generative Adversarial Network
- CT - Computed Topography
- LSTM - Long short term memory
- AUC - Area under curve
- DCNN - Deep Convolutional Neural Network
- RCNN - Regions with CNN Features

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## **Abstract**

This paper aims to analyze the applications of Generative Adversarial Networks in overcoming issues of data-shortages in relation to COVID-19. There are many COVID-19 data-sets compiled but some suffer from lack of data-quality and data shortages[1][2]. In this paper I aim to create and train a convolutional neural network or CNNs to analyze X-Rays of patients lungs to automate the detection of COVID-19. The CNN will be trained with a number of images generated from different GAN architectures to determine which will prove most efficient in automating the detection of COVID-19. I also aim to use the GANs in conjunction with one and other to try out different combinations to see if feeding images generated by one GAN to other GANs will produce more accurate results when training the model.

# Chapter 1

## Introduction

### 1.1 Generative Adversarial Network (GAN)

A generative adversarial network or GAN for short first appeared in a 2014 paper by Ian Goodfellow et al[3]. In this paper Goodfellow et al propose a new way to generate data via an adversarial process. The GAN essentially works as follows: two models are trained, a generative model  $G$  which will generate the content from the data and another model  $D$  which will be the discriminator, judging if data created by the model came from the dataset rather than  $G$ . The goal of this training is to ensure data generated from  $G$  is realistic enough to fool the discriminator  $D$  into believing that the generated content came from the training set. It is in this way that we can create realistic "fake" data from the generative model.

There are a number of GAN architectures which are useful in different scenarios, such as CycleGans[4] which are useful for translating images from a source domain  $X \rightarrow Y$  in which  $Y$  is the target domain, StyleGan which was created by NVIDIA which allows more control over the generative process[5] and PixelRNN which can recreate images when given a fraction of the original and can generate new images based on probability[6].

In this dissertation I will examine a number of different generative adversarial network architectures and will use them in conjunction with each other, by feeding content generated by one architecture into another to develop a more diverse training set for the final model.

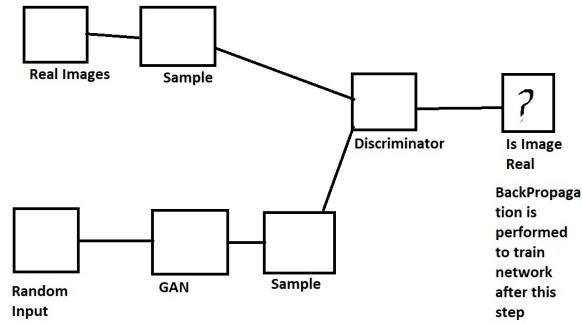


Figure 1.1: Basic Example of generative adversarial network

As we can see from the image above, we start the process by taking a sample of real images from the training data, then passing it to the discriminator. We also take a sample from the GAN created images and pass that to the discriminator which will then determine if the images are real or fake. After the discriminator determines if the image is real or fake then backpropagation is performed to train the model so that it can differentiate better between samples which came from the training set and those which came from  $G$ .

## 1.2 What is An Artificial Neural Network? (ANN)

An artificial neural network, or ANN for short, is a network of neurons or nodes which are used for training a model to perform a certain task. They are made up of an input layer,  $N$  hidden layers, and finally an output layer. Each layer has its own activation function, and will adjust its weights and biases to determine the final output of the model.[7] These networks are heavily inspired by biological processes which occur in the brain.

artificial neural networks are a general purpose model used to solve a number of common problems.

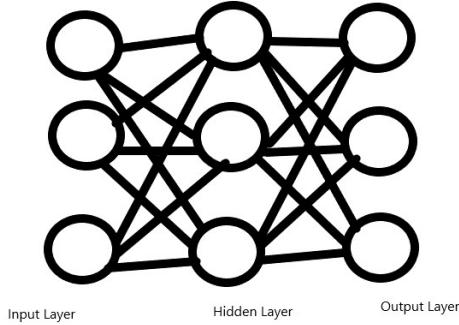


Figure 1.2: Basic Example of Artificial Neural Network

A basic example of an artificial neural network is shown in Figure 1.2. As shown in the figure, the network has an input layer, a hidden layer, and an output layer. Generally when creating these networks we determine the number of neurons in both the input and the output layers based on the different classifications we are trying to predict. The above network could be used to predict if an image is of a cat, a dog or a fish for example. There can multiple hidden layers in an ANN and the number of neurons in each layer can be adjusted. In reality Artificial Neural Networks will typically be far bigger than the example given above in terms of neurons and hidden layers but for illustrative purposes the above diagram will suffice. Each neuron will also have its own weights, biases and activation function which will determine whether a neuron fires or not. Common activation functions include ReLU (Rectified Linear Units), Sigmoidal function and tanh.

### 1.3 What is A Convolutional Neural Network? (CNN)

A convolutional neural network, or CNN for short, is a type of neural network which is primarily used for tasks involving image and pattern recognition[7] The structure is similar to an ANN in which we have an input layer,  $N$  hidden layers, and finally an output layer. As with the Artificial Neural Network each of these layers will have an activation function and it's own weights and biases to determine the final output for a given input. The model will take an image as input, the image is made up of vectors (RGB) or a similar format and from that image the model will determine certain patterns. For example, the output might be a classification of whether or not Covid-19 is present or not. This application will be discussed in more detail later in the dissertation.

There are a few ways in which CNNs differ from ANNs, in that they are comprised of three types of layers which are the convolutional layer, the pooling layer and fully connected lay-

ers[7]. The convolutional layer is responsible for determining the output of a given input (for example if we were trying to detect images of cats then this layer would activate 1 for a cat and 0 for images which were not cats), the pooling layer will reduce the parameters of a given input by means of downsampling, and finally the fully connected layers will then determine and classify the output for a given input. The convolutional layers parameters utilize learnable kernels, and this layer also produces a  $2D$  activation map which will be used to determine if a neuron fires or not for a given input. We can adjust hyper parameters in the convolutional layer to greatly reduce the complexity of the model through optimization, which can be achieved by adjusting the following hyper parameters: depth, stride and zero padding.

Depth is related to the output volume produced by the convolutional layers in the model which can be manually set by adjusting the number of neurons in each layer. Reducing the depth of the model can greatly decrease the training time but at the expense of performance. Stride is related to the spatial dimensionality of the input which will determine the receptive field (every neuron is connected only to a small region of the input this region is referred to as the receptive field[7]), if the stride is set to a low integer we will produce extremely large activations, and if it is set too high we won't produce enough activations.

Finally, zero-padding this will pad the border of the images ingested by the model reducing their dimensionality, padding is useful for increasing the accuracy of the model as it can possibly eliminate areas of the image which are not useful for the model and can also improve training time times in some use cases.[8]

Through the adjustment of the hyper parameters mentioned above, and through the utilization of different activation functions, the accuracy of the convolutional neural network can be improved through a process of trial and error.

## 1.4 Supervised Learning

Supervised learning is a type of learning involving labelled data to train the model[9]. The data is labelled manually by a data scientist which can be a long and laborious process depending on a number of factors (size of the data, number of classes, etc.), but offers many benefits when it comes to training models. Supervised learning performs extremely well at tasks involving classification (classifying data into a given category), and regression (understanding the relationships between independent and dependent variables).

## 1.5 Unsupervised Learning

Unsupervised learning is a type of machine learning which involves using unlabelled data to train machine learning models[9]. This type of machine learning requires no human interven-

tion since the data is unlabelled and will detect relationships between data based on the raw data fed in to the model. This type of machine learning is used for the following tasks: clustering(grouping data together based on shared characteristics or features), association(Finding relationships between features), and dimensionality reduction (Reducing the number of features in a given dataset without compromising the integrity of said data). The key differences between supervised and unsupervised learning are: labelled vs unlabelled datasets, and finding relationships in data (unsupervised) or trying to predict and classify data (supervised). In this dissertation we examine the use of both labelled and unlabelled datasets to train and test the model.

## 1.6 Tensorflow

Tensorflow is an open-source library used for machine-learning and artificial intelligence research worldwide[10]. Tensorflow provides numerous modules and classes which form the foundation of building both the generative adversarial network and the convolutional neural network. There have been numerous case studies proving the efficacy of Tensorflow in solving many AI / ML problems and the library is used by research teams in organisations such as Google, Airbnb, ARM, Coca-Cola, Intel, and many more[11].

Given the reputation and widespread use of Tensorflow, and the vast amount of documentation around the framework it seems an ideal library for the implementation of GANs and CNNs for this study.

## 1.7 Keras

Keras is a deep-learning framework for Python which provides a number of helpful functions and methods for creating and training the CNN[12]. Keras is built on top of Tensorflow and simplifies data loading, pre-processing and the overall building of the model. Keras is commonly used by data-scientists and researchers due to the powerful methods it offers and the time it saves. The additional classes and modules Keras provides on top of Tensorflow will help to reduce the time taken to build and develop of building both the convolutional neural network and the generative adversarial network.

Like Tensorflow, Keras has been used by a number of companies and is well recognised in the Artificial Intelligence community. Its uses include Computer Vision, Natural Language Processing, Generative Deep-Learning and Reinforcement Learning amongst others[13].

## 1.8 Background of Problem & Aims of This Paper

COVID-19 is a highly transmissible virus which has caused a worldwide pandemic and has claimed many lives. There have been 616,951,418 cases worldwide and 6,530,281 deaths as of the 4th of October 2022[14]. During the pandemic, Ireland alone had a total of over 1.6 million confirmed cases and nearly 8,000 deaths[15]. This has led many researchers to pursue the goal of automating the detection of COVID-19 to partially relieve the immense pressure put on medical staff throughout the pandemic.

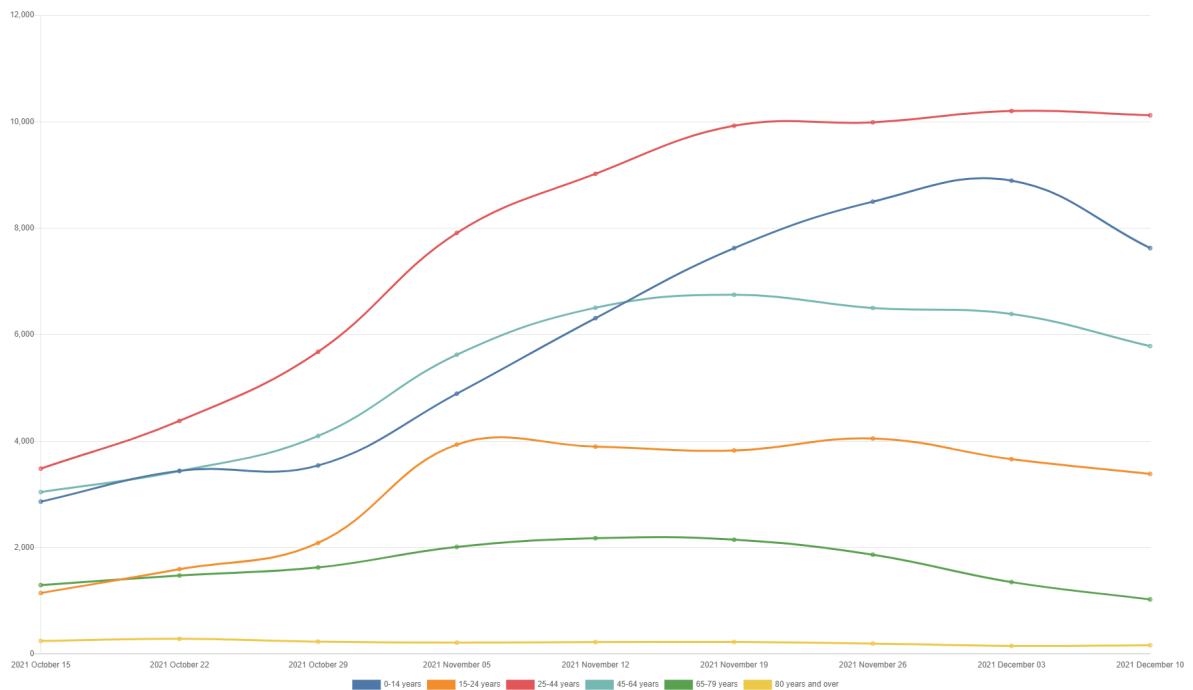
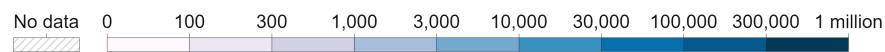


Figure 1.3: Graph of COVID-19 Statistics by age-range Ireland from October 2021 - December 2021 Courtesy of CSO[16]

Cumulative confirmed COVID-19 cases per million people, Oct 9, 2022  
Due to limited testing, the number of confirmed cases is lower than the true number of infections.

Our World  
in Data



Source: Johns Hopkins University CSSE COVID-19 Data

CC BY

Figure 1.4: Cumulative cases of the COVID-19 virus world-wide courtesy of Our World in Data[17]

The main objective of this research is to develop a robust model which can accurately analyze X-Rays of patients and determine from said X-rays if the patient is afflicted with COVID-19. This will be achieved by utilizing a number of different GAN architectures which will create realistic "fake" data which will then be used to train a number of models. From this training I plan to compare and contrast the results when generating data with different architectures to determine the best configuration for data generation to train the CNN model. There has been some success in utilizing convolutional neural networks to automate the detection of the virus[18][19]. Through the use of data-augmentation utilizing a variety of GAN architectures that such Convolutional Models will be improved upon and made more accurate.

I plan on utilizing existing data sets which I will list in the next section when training the Generative Adversarial Models, through trial and error I plan on determining the best architecture of GANs to use for training the model for this use-case.

## 1.9 Datasets

### 1.10 About the datasets

Before beginning the training of the model it is important to explore and understand each of the datasets. There are a total of three datasets which will be used in the course of this research, I will explain more about these datasets below.

#### 1.10.1 COVID-19 Chest X-ray

The COVID-19 Chest X-ray data set is a data set which is comprised of labelled X-Ray Images taken from a number of patients. This dataset contains 357 X-ray images of COVID positive patients, and Chest X-Rays of those afflicted with another disease (MERS, SARS, and ARDS). This dataset also includes a metadata file listing the diagnosis of the patient along with a number of other features.

#### 1.10.2 COVID-19 Radiography Database

The COVID-19 Radiography Database is made up of 3,616 images of chest X-Rays taken from COVID positive patients, 10,192 Images of lung X-Rays taken from healthy patients, and 1,345 X-ray images of viral pneumonia positive patients. All images in this dataset are PNG (Portable Network Graphic) images and are at a resolution of height 299 pixels and width 299 pixels eliminating the need for pre processing of the images, the dataset also includes metadata for each of the images in this dataset showing a number of features with the diagnosis of the patient as well. This data in this dataset was gathered by a team of researchers from Qatar University, Doha, Qatar, and the University of Dhaka, Bangladesh along with their collaborators from Pakistan and Malaysia.

#### 1.10.3 COVID-19 Pneumonia Normal Chest Xray PA Dataset

The COVID-19 Pneumonia Normal Chest X-Ray PA dataset is comprised of a train set containing 74 Normal X-Ray Images taken from healthy Patients and afflicted with Pneumonia and a test-set containing a Normal set containing 20 chest X-Rays taken from healthy patients and a Pneumonia set containing 20 images. The images in this dataset are unlabelled and no metadata is offered, however the images are segregated into separate files listing the diagnosis.

#### **1.10.4 Use of datasets in This Project**

I plan to use each of these datasets to train and test the model and use data-augmentation to increase the train and test-sets by utilizing Generalized Adversarial Networks. When using these datasets in conjunction it is my hope that the GAN will have enough data to be effective when generating new sample images to train the final model.

### **1.11 Structure of This Thesis**

This thesis is broken into 6 chapters in total, this section will include the headings of the chapters and a brief summary of each chapter below:

#### **1.11.1 Chapter 1 - Introduction**

This chapter will offer the reader of this thesis a brief introduction to a number of core concepts which will be necessary to understand before diving deeper into this thesis. It is important that the reader has a basic understanding of generative adversarial networks, convolutional neural networks, artificial neural networks, supervised & unsupervised learning, and the overall question that this research proposes before discussing the implementation or discussing pertinent literature in this field.

In this section I will frame the research question, explain what a generative adversarial network is, its function, and how it works, I will also explain artificial neural networks and convolutional neural networks, and I will discuss the basic methodologies relating to the implementation of this project. I will also discuss the libraries used to implement the practical artifact, datasets used to train the model and give the reader of this thesis a clear understanding of the key aims of this research.

#### **1.11.2 Chapter 2 - Literature Review**

In this section I will review pertinent literature related to the problem domain and discuss the ideas and concepts presented in these papers. I will also review the results from the research conducted in these papers and use them as a metric to gauge the performance of my own model. The papers will also be compared and contrasted and I will discuss the findings and how useful these papers were when conducting my own research. It is very important to understand the problem domain before beginning implementation of this project to ensure that I am not "reinventing the wheel". This section will also provide the reader of this thesis with the most up-to-date progress made within the problem domain.

### **1.11.3 Chapter 3 - Implementation**

In this section I will discuss the architecture of the convolutional model, the various architectures of generative adversarial networks implemented, how the models were trained and the overall design of the code implemented and the rationale behind certain design choices. I will also show the results from training the models and discuss how through trial and error I was able to improve the various models and will include code samples so that the models can be reviewed by the reader or re-implemented by them.

### **1.11.4 Chapter 4 - Results**

In this section I will review the results achieved from training the best models and suggest how they may possibly be improved. I will be showing lots of graphs / tables in this section to gauge each model's test / dev set errors and I will also be comparing and contrasting the effects of the different GAN architectures implemented as well as discussing the results of the convolutional model.

### **1.11.5 Chapter 5 - Further Research and Conclusions**

In this section I will discuss further research that may need to be done by any researchers who would like to build upon this research. I will also review where the models could be improved and what I'd do differently if I were to conduct this research again. I will also discuss common issues I faced during the implementation of this project and how I overcame them. This section will be a summary of all the research conducted, the code, and my experience overall throughout the writing of this thesis.

This will be the final section of the paper and will tie the entire thesis together.

## **Chapter 2**

# **Literature Review**

### **2.1 Introduction to Literature Review**

The first reported cases of COVID-19 occurred in Wuhan, China on December 12th, 2019[20], when a number patients began to exhibit "symptoms of an atypical pneumonia-like illness that does not respond well to standard treatments". It was not until December 31, 2019 that the World Health Organization(WHO) Country Office in China was informed of several more cases of this strange virus described as "pneumonia of unknown etiology", the symptoms of this new virus were shortness of breath, and fever. All the initial cases observed seem to have been connected to a market called Huanan Seafood Wholesale Market. On January 1st of 2020 the Huanan Seafood Wholesale Market was shut down amid concerns over the spread of this new virus. On January 3rd the Government of China alerted the World Health Organization that they had identified over 40 new cases of this pneumonia-like disease, on the 5th of January, Chinese public health officials shared the genetic sequence of the new virus with the world through a database that could be accessed by the public. Following the release of this information the CDC(Centers for Disease Control and Prevention), which is a US Government funded heath-care research agency, began an investigation into the origins of this new virus. The origins of COVID-19 are not clear and are still being researched, the most likely explanation offered by scientists is that it originated in the Huanan Seafood Wholesale Market from animals sold there, a likely culprit is the Raccoon Dog which are used for fur and food in China[21] but other theories suggest that a lab leak at a biological weapons facility[22] may be responsible for the creation of the virus. Some researchers are currently suggesting that blood samples taken from animals sold at the Hunan Market and samples from the people who sold them may lead to definitive evidence of the diseases origins[21].

Although the origins of COVID-19 still remain up for debate one thing is very clear when studying the virus, it's high transmission rate and the speed at which it can spread made it one of the deadliest viruses in human history.[23][24].

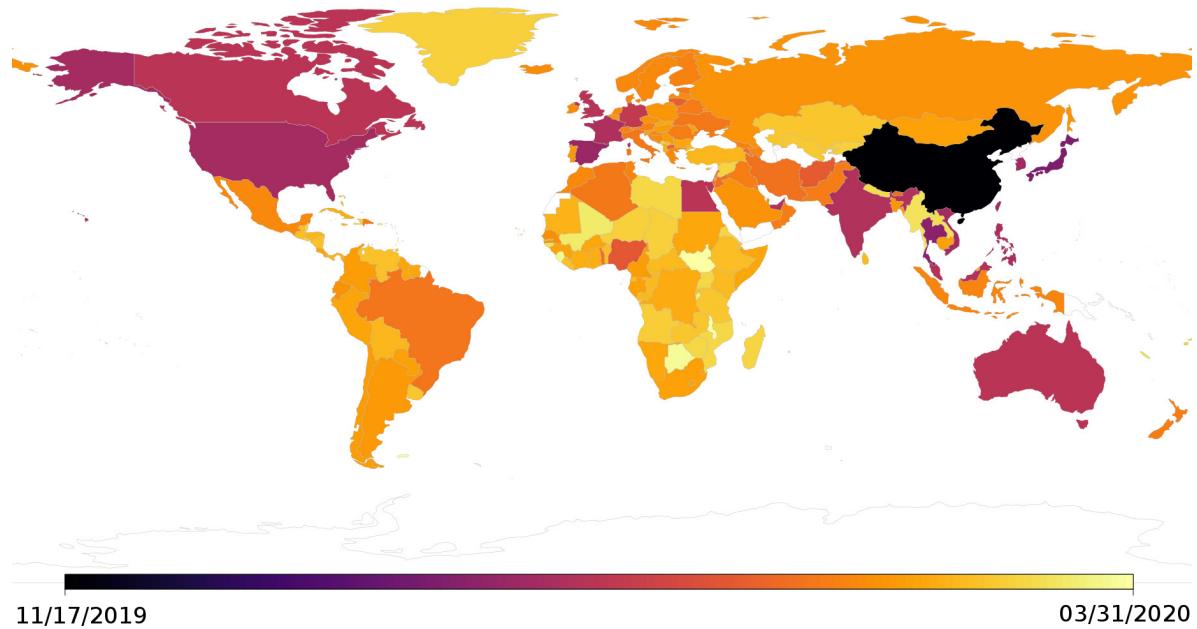


Figure 2.1: Estimated dates of first COVID-19 cases around the World, Image courtesy of Roberts,Roszman and Jarić[25]

Due to this rapid spread of the virus many governments were unprepared for dealing with such an outbreak. The Artificial Intelligence community had published many papers and conducted much research into designing automated tools which could relieve medical professionals of the extreme stress they were under, unfortunately most of the models trained were of no use to medical professionals and some were even deemed harmful[26]. There were many limitations when it came to training automated diagnostic tools for COVID-19 such as incorrect assumptions about the data, lack of data quality and lack of data in general. Due to the lack of quality data and the urgent need for diagnostic tools many of the models were trained using poor quality data or incorrect data. Such poor models would have had drastic effects if patients who were COVID positive were diagnosed as negative by the model, models suffering from high false-negative rates would have drastic consequences for the patients afflicted with COVID.

The models trained on what have been termed as "Frankenstein Datasets" suffered immensely as some of the data came from the same source meaning the same data from the training set could have been present in the test set, this would severely impact the performance of the model as it would have overfit on the data from which it was trained. These models which were overfit on the data would seem to have a high accuracy but ultimately would perform poorly on real world data.

	<b>Underfitting</b>	<b>Just right</b>	<b>Overfitting</b>
<b>Symptoms</b>	<ul style="list-style-type: none"> <li>• High training error</li> <li>• Training error close to test error</li> <li>• High bias</li> </ul>	<ul style="list-style-type: none"> <li>• Training error slightly lower than test error</li> </ul>	<ul style="list-style-type: none"> <li>• Very low training error</li> <li>• Training error much lower than test error</li> <li>• High variance</li> </ul>
<b>Regression illustration</b>			
<b>Classification illustration</b>			
<b>Deep learning illustration</b>			
<b>Possible remedies</b>	<ul style="list-style-type: none"> <li>• Complexify model</li> <li>• Add more features</li> <li>• Train longer</li> </ul>		<ul style="list-style-type: none"> <li>• Perform regularization</li> <li>• Get more data</li> </ul>

Figure 2.2: Examples of Overfitting, Underfitting and Optimal models, Image courtesy of Abhishek Shrivastava[27]

The figure above2.2 shows how a model's performance can be analyzed, underfitting yields a high training error and high bias meaning that the model will perform poorly on the training, test, and dev sets. Overfitting would have a very low training error which will be lower than the test, and dev set error and wouldn't be fit for purpose when analyzing real world data. The optimal model has a training error that is slightly lower or in and around the same accuracy as the test and dev sets.

The lack of medical experience also played a role in the poor performance of these models as many of the AI researchers training these models would be unfamiliar with flaws in the data. Bias of the radiologist labelling the X-rays of patients also played a role as the radiologist could have inaccurately diagnosed the patient as COVID positive or negative. Private Artificial Intelligence companies also played a role in poor model development as published models from researchers tied to the company also showed that these models had a high risk of bias.

As the pandemic progressed more and more data was made available to researchers which was able to mitigate some of the problems stated above leading to more accurate and robust models which we will explore in the later sections.

## **2.2 Analysis of Existing Models for Automated COVID-19 Detection**

In a paper entitled "A Deep Learning-Based Diagnosis System for COVID-19 Detection and Pneumonia Screening Using CT Imaging"[28] researchers investigated a deep-learning approach to creating a diagnostic tool for COVID-19. The research involved utilizing data taken from Computed Topography scans. These scans segmented the infected regions of a patients lungs to determine if said patient was afflicted with the COVID-19 virus. The researchers also used a technique called "Contrast Limited Adaptive Histogram Equalization" which is a pre-processing method which removed noise and intensity to create a homogeneous data set. The researchers also removed black slices from the images so that only the region of interest was highlighted, further enhancing the performance of the model. U-Net architecture, which is based on Convolutional Neural Network encoders and decoders, was used in the creation of this model to allow for a more timely and accurate image segmentation to generate the lung and infection segmentation models. Four-fold cross validation was then used to analyze the performance of the model along with a three-layered CNN architecture which was comprised of additional fully-connected layers followed by a softmax output layer which was used for classification of the images.

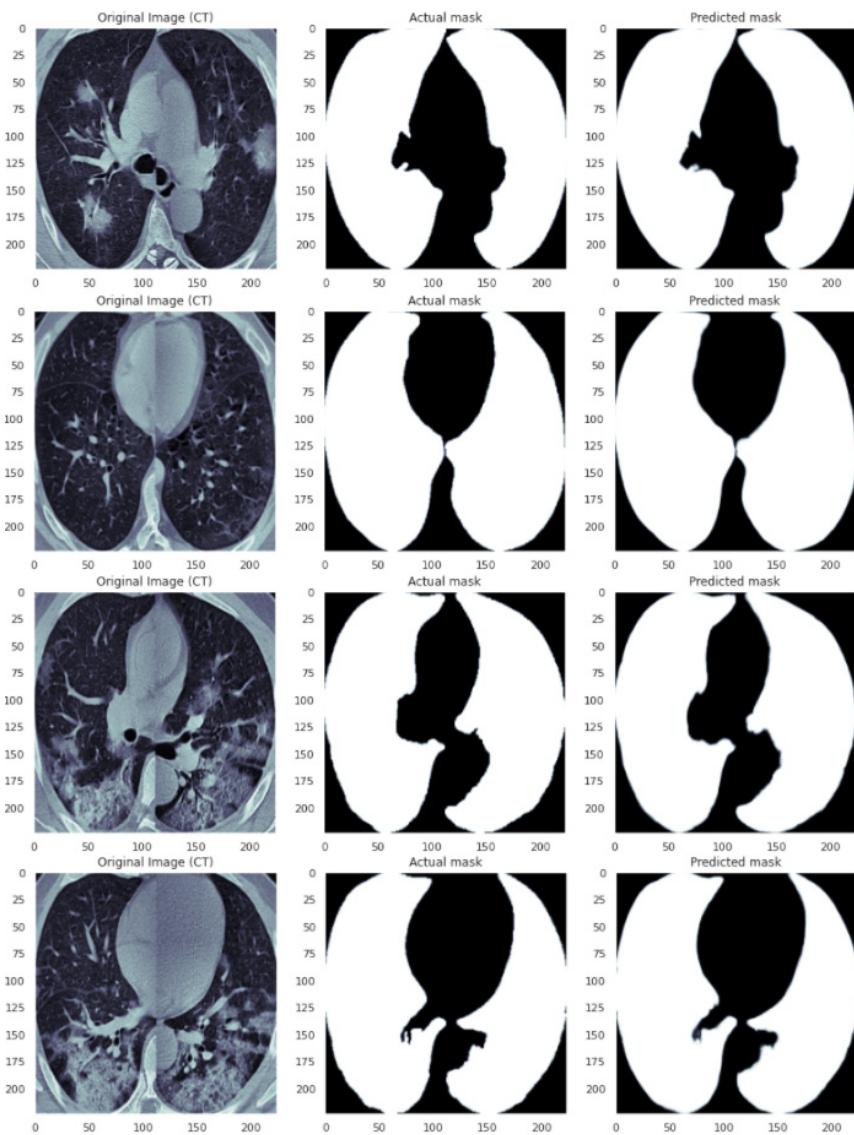


Figure 2.3: Examples of CT Qualitative images lung segmentation[28]

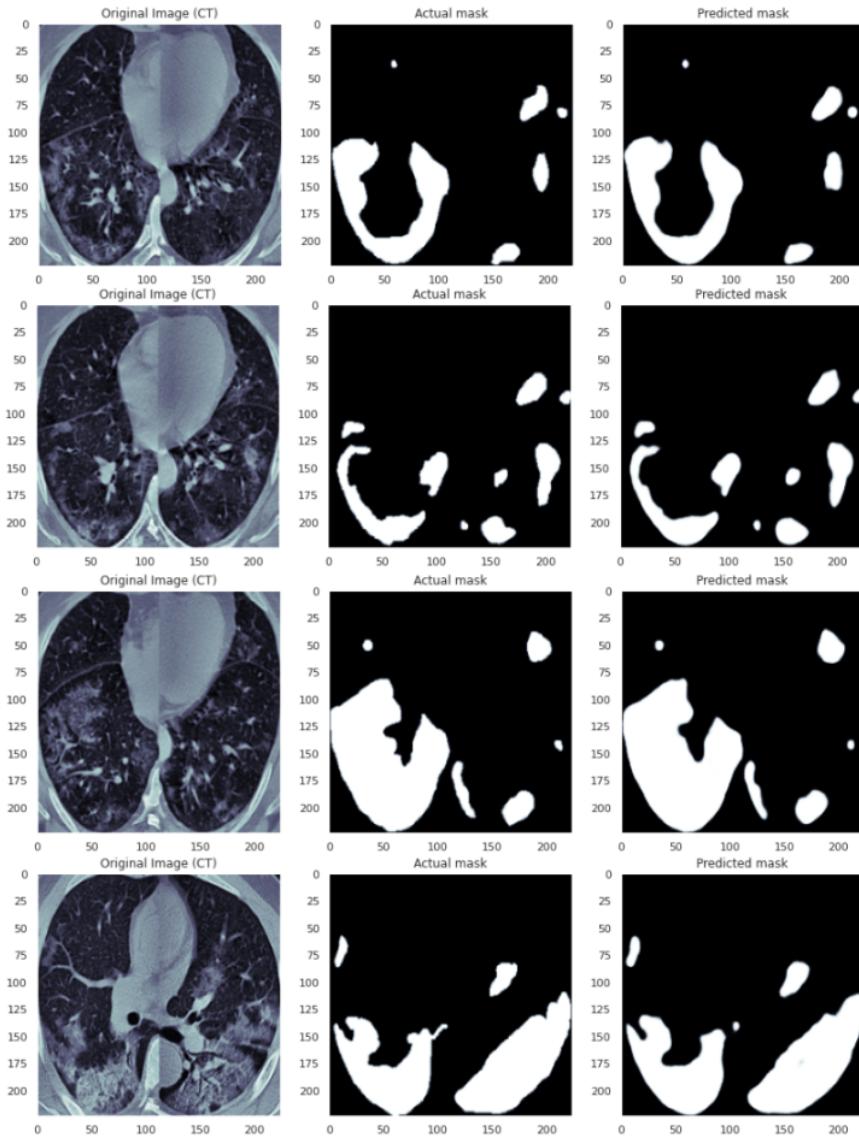


Figure 2.4: Examples of CT qualitative images infection masks[28]

The first image2.3 shows the result of the lung segmentation results between the ground truth and the researchers proposed four slice model which is compromised of four slices taken from different CT Scans. first column: original CT scan,second column: ground truth, third column: predicted lung masks

In the second image2.4 we can observe the qualitative comparison between the researchers infection segmentation results which is made up of four slices from different CT scans and the ground truth. First column: original CT scan, second column: ground truth, third column: predicted infection masks

Utilizing a 70% - 30% training set and validation set split the researchers demonstrated that the proposed system achieved a dice score of 0.98% and 0.91% for lung and infection segmen-

tation tasks. Additionally the system accurately diagnosed patients afflicted with COVID-19 0.98% of the time. The development of this model suffered from lack of data as only 20 CT scans were used to train and the model, the limited data set used suggests the researchers model may have possibly been overfitting the training data. The researchers mention as much in the conclusion section of this paper "The main limitation of this study is the use of a small, but sufficient number, of model training data. Confidentiality restrictions and the high cost of labeling partly explain the absence of a large number of COVID-19 clinical CT images. Indeed, combining datasets collected under different labeling regimes is often problematic because, in general, the data collected is heavily influenced by the instructions provided to annotators". From the quoted section of this paper there it is shown that there is a high potential for bias in the data set used by the researchers. The possibly mislabelled images links back to the "Frankenstein Datasets" which I mentioned in the introduction section to this literature review.

In another paper entitled "A combined deep CNN-LSTM network for the detection of novel coronavirus (COVID-19) using X-ray images"[29] we see a new method being used by researchers to develop an automated diagnostic tool. The researchers decided to use a combination of a convolutional neural network with LSTM (long short-term memory), they used the convolutional neural network for deep feature extraction and LSTM for detection of COVID-19 using an extracted feature. They also used a dataset containing 4575 X-ray images which included 1525 images of COVID-19 X-rays. The experimental results of the system are as follows: 99.4% accuracy, AUC (area under curve) accuracy of 99.9%, specificity of 99.2%, sensitivity of 99.3% and finally an F1 score of 98.9%. The researchers suggest that this system could be further improved in the abstract if more data were available to the researchers.

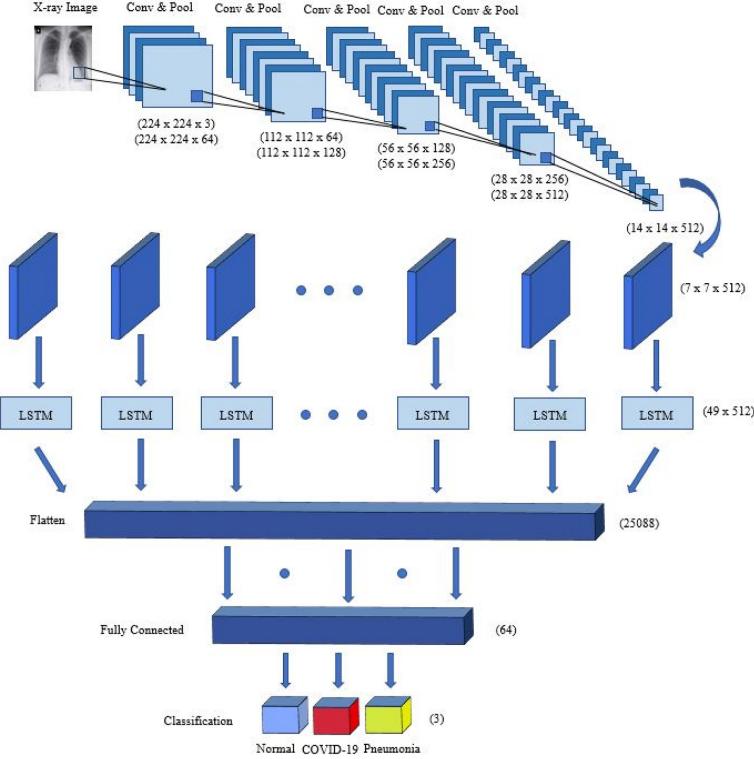


Figure 2.5: Diagram of how LSTM works[29]

The model benefited from the use of LSTM as an LSTM network has an internal memory which is utilized to learn from experience with long term states. LSTM is based on recurrent neural networks, and improves upon them by using memory blocks instead of conventional RNN units, this helps to solve the vanishing and exploding gradient problem[30]. In addition to the memory blocks there is also a cell state which saves long-term states, the cell states being the main difference between recurrent neural networks and LSTM. The network is capable of remembering and connecting previous information to present data[31]. The LSTM Network is comprised of three gates the input gate which is termed the "forget gate", an update gate, and finally an output gate. These gates essentially determine which data is worth remembering and which data can be forgotten.

The researchers included diagrams of each models results which I will include below so that the reader can compare and contrast each model.

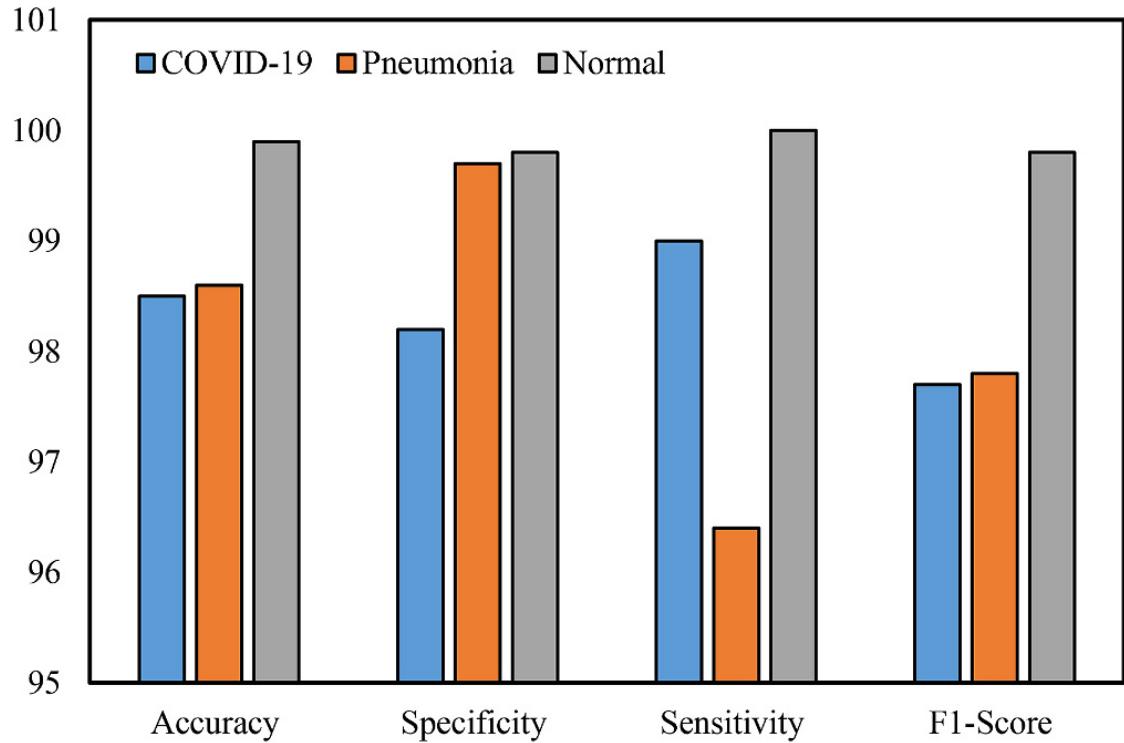


Figure 2.6: Performance of CNN model[29]

The image above shows the performance of a standard CNN model the accuracy ratings are as follows:

Class	Accuracy	Specificity	Sensitivity	F1-Score
COVID-19	98.5	98.2	99.0	97.7
Pneumonia	98.6	99.7	96.4	97.8
Normal	99.9	99.8	100.0	99.8

Table 2.1: Results of Standard CNN Network - A combined deep CNN-LSTM network for the detection of novel coronavirus (COVID-19) using X-ray images

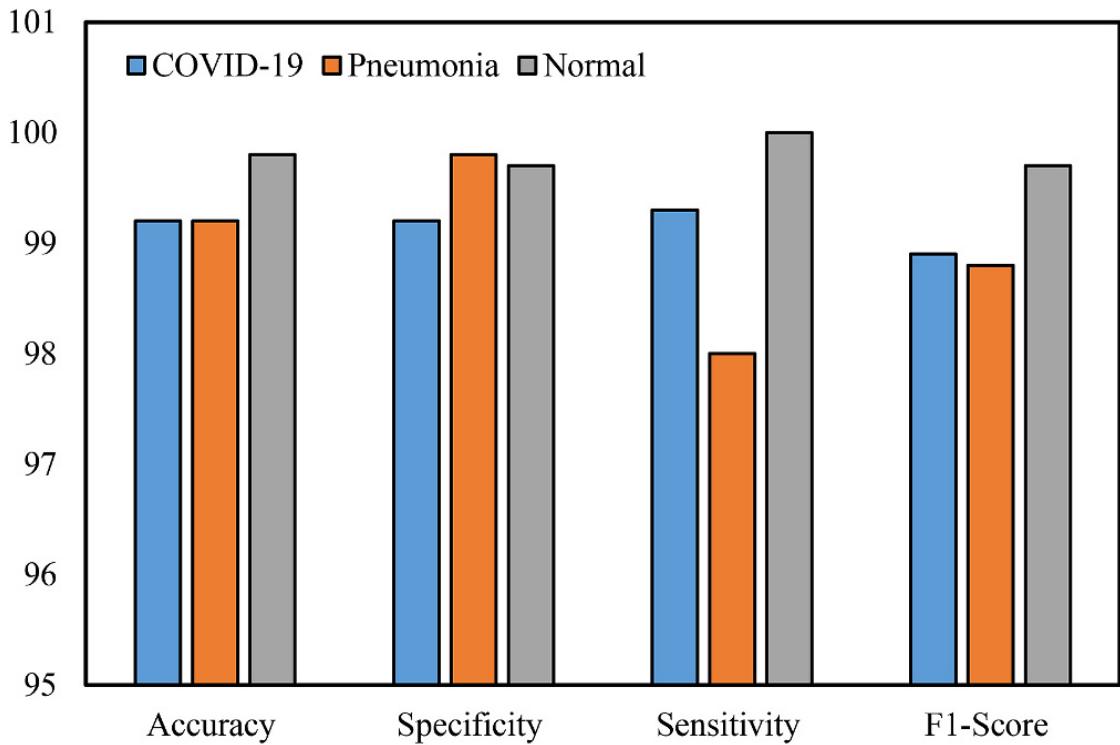


Figure 2.7: Performance of CNN LSTM Model[29]

Class	Accuracy	Specificity	Sensitivity	F1-Score
COVID-19	99.2	99.2	99.3	98.9
Pneumonia	99.2	99.8	98.0	98.8
Normal	99.8	99.7	100.0	99.7

Table 2.2: Results of CNN - A combined deep CNN-LSTM network for the detection of novel coronavirus (COVID-19) using X-ray images

From the above image is is clear that the model utilizing LSTM outperformed the basic CNN model on almost all fronts (with the exception of classification of normal patients which experienced a small decrease in accuracy), yielding a higher accuracy, specificity, sensitivity and F1 score for identifying COVID-19, and Pneumonia from X-rays.

Despite the results achieved by the model, the final model suffers from lack of data which the researchers address in the conclusion section of this paper. The other short-coming of this model is that it focuses on posterior-anterior view of X-Rays meaning that it cannot diagnose

X-Rays which are in other formats. The authors of the paper also address that X-Rays where the patient is afflicted with multiple diseases cannot be efficiently classified by the model and the model's accuracy was not compared with that of radiologists. Data-augmentation may prove useful for such a model using a combination of CNN and LSTM.

### **2.3 Challenges & Limitations of Using Artificial Intelligence in Automated Diagnosis Systems for COVID-19**

In a paper entitled "Artificial intelligence in the diagnosis of COVID-19: challenges and perspectives" [32] researchers offer an analysis of the challenges of developing Artificial Intelligence to aid in the diagnosis of COVID-19. As spoken of previously in this thesis the challenges include: lack of data, lack of data quality and the use of poorly merged data sets termed as Frankenstein data sets when training models. There are, however, more challenges that are faced when developing diagnostics tools, as discussed in the previously cited paper it is very difficult to find people who are COVID-19 positive and asymptomatic due to them not getting treatment as no symptoms are apparent. The labelling of data is also an issue as the X-rays of patients may only show moderate signs of COVID-19 which yields a risk of mislabelled data by clinicians. There is also a risk of false positives and false negatives when developing a diagnostics tool. False positives would cause a patient to unnecessarily be quarantined and false-negatives could cause a patient to inadvertently spread COVID-19 to others. Some patients who have already been infected with the virus may show no signs on CT Images which also yield high false negative rates making it difficult to distinguish COVID positive patients from COVID negative patients.

To mitigate these challenges the researchers suggest that when developing an Artificially Intelligent diagnostic system the developer should combine chest imaging, exposure history and laboratory tests when training and testing the model. Such data, however, is hard to come by as there are multiple laws concerning data-collection and ethical questions regarding the patients right to privacy.

### **2.4 Research into Data Augmentation And Convolutional Neural Networks Architectures**

Data augmentation allows Artificial Intelligence researchers to artificially inflate the size of the amount of data, this is done by utilizing existing data and detecting patterns in the data. From the original data new data is produced using various methods such as rotating images, applying filters, altering various aspects of the image(such as padding, cropping and zooming) etc. There are numerous techniques and methodologies for using data augmenta-

tion but for the purpose of this thesis I will be using Generative Adversarial Networks to create new data<sup>1.1</sup> for the purpose of improving upon existing automated diagnostic models for COVID-19. There are multiple different types of GAN architecture which I have covered in the introduction section of this thesis. The key advantages of using data-augmentation are as follows: larger training set to train models on, reduces overfitting and helps to prevent underfitting of the model, reduces costs / time of collecting new data, and increases the ability of the trained model to generalize. There are however some challenges when it comes to using data augmentation such as: inability to reduce bias of new data(if there is bias in the existing data the new data will also contain bias), hard to generate discrete data such as text, and the data generated will need to be evaluated.

In a paper entitled "Data Augmentation Using GANs"[33] the researchers outline two algorithms to oversample the minority class within the data with the aim of balancing the data set. These two methodologies are called SMOTE (Synthetic Minority Over-sampling Technique)[34] and ADASYN (Adaptive Synthetic Sampling Approach for Imbalanced Learning)[35].

SMOTE works by creating artificial samples based on the position of the data, it selects a random point in the least represented class of data and identifies data of the same class using the K-Nearest Neighbour algorithm which is a form of unsupervised learning. For each pair a new point is generated in the vector between the two pieces of data, the new point is then positioned in a random percent away from the original point.[33]

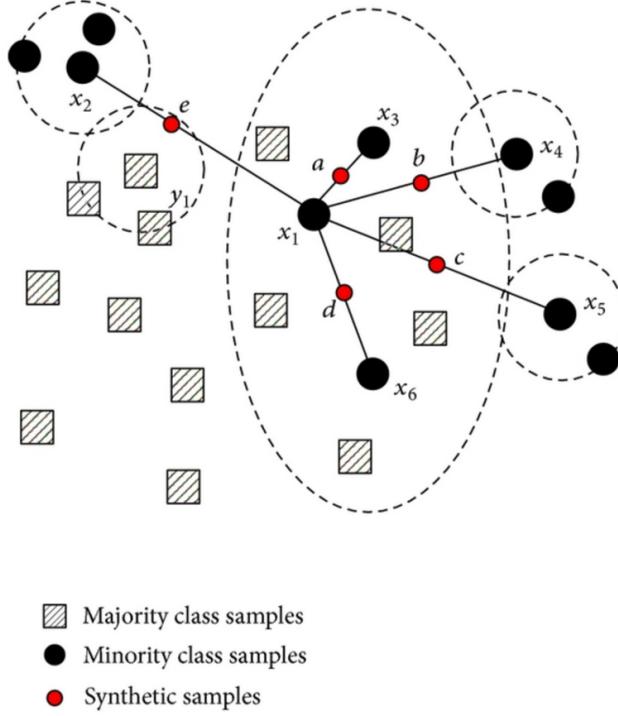


Figure 2.8: Example of SMOTE[34]

As we can see from the above diagram 2.8 the algorithm functions by detecting points between minority class samples, the points being determined by the K Nearest Neighbour algorithm. This ensures that the newly generated data will be similar to the already existing data of the minority class. This may prove useful when developing the Generative Adversarial Network to create Synthetic COVID-19 X-Rays.

ADASYN works in a similar way to SMOTE and was originally based on SMOTE. They function in much the same way but the key difference lies in ADASYN adding a random small bias value to the points, breaking linear correlation to their parents. The bias which ADASYN adds helps to increase the amount of variance within the synthetic data. In this research paper the authors decided to evaluate the utility of GANs to generate synthetic numerical data in two domains, one domain is concerned with training a classifier using purely synthetic data and the other domain to balance a data set by oversampling the minority class using synthetic data. The first domain's performance was measured by comparing the classifier's performance on the original data set with the classifiers performance on the synthetic data set which will be created by variations in the GAN architecture. The researchers gauged the performance of the second domain by comparing the performance of the classifier on imbalanced data oversampled with a standard GAN, SMOTE, and ADASYN as well as the original data set which is not oversampled. SMOTE and ADASYN produce desirable results but the drawback

is that they do not generalize well with sparse data and outliers according to the researchers. In both experimental domains the researchers used the following GAN architecture to generate the synthetic data

- Leaky ReLU as activation function with a negative slope of 0.2
- batch size of 5
- learning rate of  $2 \times 10^{-4}$
- use of dropout in the GAN generator with a probability of 0.3
- Binary cross-entropy as loss function
- ADAM as the optimizer
- No convolution layers
- If the generator has more than one layer they are ordered in ascending size
- In the discriminator layers are ordered in descending size if there is more than 1 layer

[33] They also used the following architectures to generate the data:

Data Set Name	Architecture of GAN
Original Data	The first 70% of the original database
256/512/1024	Generated by a GAN with 3 hidden layers with size 256, 512 and 1024
256/512	Generated by a GAN with 2 hidden layers with size 256 and 512
256	Generated by a GAN with 1 hidden layer with size 256
128/256/512	Generated by a GAN with 3 hidden layers with size 128, 256 and 512
128/256	Generated by a GAN with 2 hidden layers with size 128 and 256
128	Generated by a GAN with 1 hidden layer with size 128

Table 2.3: GAN Architectures used for experiments(Data Augmentation using GANs paper[33])

Many of the choices the researchers made when designing the GAN were chosen due to them being standard among researchers. The performance of the GAN was then tested on 3 data sets which are listed below.

- Pima Indians Diabetes data Database
- Breast Cancer Wisconsin Data Set (Diagnostic)
- Credit Card Fraud Detection

Using these data sets the researchers conducted a number of experiments to judge the performance of data-augmentation when testing the classifier. Experiment 1 involved training the classifier using the synthetic data generated by the GAN. The GAN was trained on the original data set for 1500 epochs. After training the GAN was then used to generate synthetic data containing the same amount of data as the original data set. The classification label used by the GAN is a continuous value between 0 and 1, the value is then made discrete(either 0 or 1) by rounding it off to the closest integer. The synthetic data was then used to train a classification tree and the tree was then tested using the test subset of the original data set. The GAN was trained using labelled class data also, this means that the synthetic data can have any class and the GAN itself determines how data should be classified. The tests for experiment one were conducted on the diabetes and cancer data sets, these data sets were not very unbalanced in terms of classes. The findings of this experiment are visible in the image below where the researchers compared classes in the newly generated synthetic data with data in the original data set.

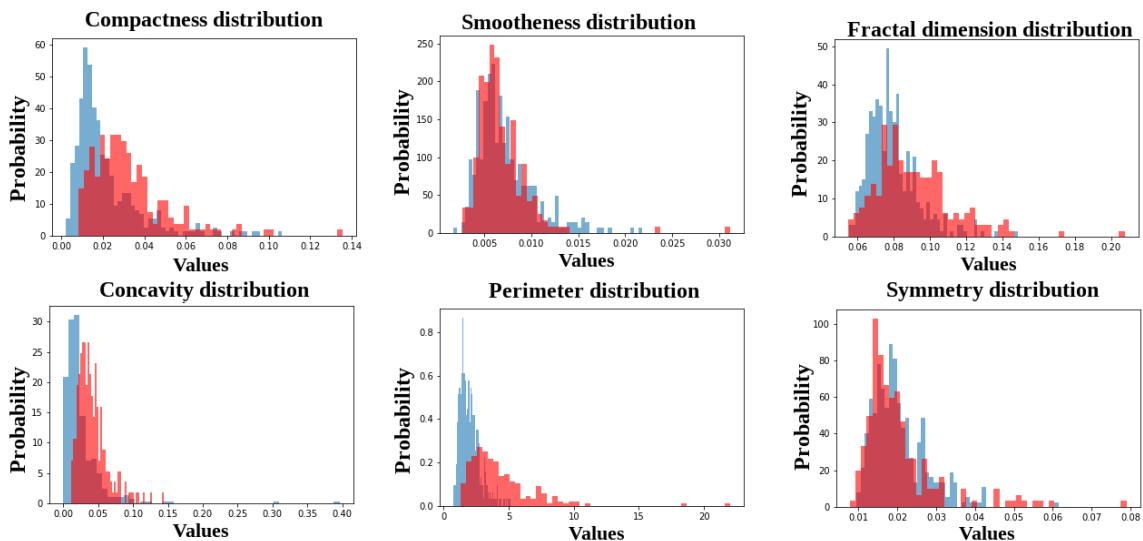


Figure 2.9: Results from Experiment One (Data Augmentation Using GANs)[33]

The blue in the image2.9 represents the distribution of features in the original data set where as the red represents the distribution of features in the newly created synthetic data. The image above shows that the synthetic data has a much more varied distribution. From using the synthetic data the researchers were able to obtain the following results:

Database	Label Proportion	Test Accuracy
Original Data Set	56.53/43.47	0.888
256/512/1024	52.26/47.74	0.818
256/512	56.28/43.72	0.941
256	56.78/43.22	0.906
128/256/512	54.02/45.98	0.953
128/256	58.04/41.96	0.935
128	54.27/45.73	0.912

Table 2.4: Results of Cancer data set using different GAN Architectures (Data Augmentation using GANs)[33]

The table above shows that classifiers trained with the synthetic data generated by the various GAN architectures had superior results than the classifier trained with the original data set. The only exception being the GAN with architecture of 256/512/1024 which showed a small reduction in test accuracy.

Database	Label Proportion	Test Accuracy
Original Data Set	64.8/35.2	0.748
256/512/1024	71.69/28.31	0.7
256/512	67.23/32.77	0.548
256	67.6/32.4	0.748
128/256/512	60.15/39.85	0.661
128/256	65.18/34.82	0.739
128	54.27/45.73	0.697

Table 2.5: Results and label distribution of Diabetes data set using different GAN Architectures (Data Augmentation using GANs)[33]

The results of classifiers trained on the GAN architectures did not perform as well as those trained on the original data set when using the Diabetes data set. As we can see from the table above the classifiers trained using synthetic data struggled to match the performance of classifiers trained with the original data set. The GAN with the architecture of 1 hidden layer consisting of 256 units did manage to match the performance of classifier trained on the original data set, the rationale for using the synthetic data would therefore be to increase the generalization of the model.

In the second experiment conducted by the researchers they tested the oversampling of the minority class in the data set by using both SMOTE and ADASYN. The following steps were used when conducting this research:

- The training set was separated based on the target class
- The GANs were trained only on minority class data
- The GAN was then used to add new synthetic data to the data set thus increasing the instances of the minority class. The researchers increased the instances of the minority class until the data set was balanced.
- The newly balanced data set was then used to train a classifier
- The classifier was then tested on two data sets the original set and the balanced version which was created by undersampling the majority class.

I will include the results obtained from this experiment below

Database	Accuracy	Precision	Recall
Original	0.999	0.896	0.556
SMOTE	0.958	0.026	0.861
ADASYN	0.958	0.026	0.861
128	0.798	0.051	0.806
256	0.986	0.077	0.789
128 / 256	0.974	0.045	0.82
256 / 512	0.964	0.033	0.808

Table 2.6: Classification results on imbalanced test set (Data Augmentation using GANs)[33]

Database	Accuracy	Precision	Recall
Original	0.782	1.0	0.565
SMOTE	0.912	0.959	0.861
ADASYN	0.921	0.979	0.861
128	0.807	0.89	0.806
256	0.894	0.998	0.789
128 / 256	0.902	0.981	0.82
256 / 512	0.888	0.962	0.808

Table 2.7: Classification results on balanced test set (Data Augmentation using GANs)[33]

It's clear from the tables above the use of SMOTE and ADASYN under performed in accuracy on the imbalanced test set but had higher recall when compared with the original. In the second table, when tested on the balanced test set, SMOTE and ADASYN outperformed the original in terms of accuracy and recall, this is due to the original data set being imbalanced, the tree trained on this data set predicts almost all samples as negative. The GAN using a

hidden layer of 128 seemed to perform very poorly in both instances when compared with other GAN architectures and this is called out by the researchers in the paper. Oversampling the minority seemed to increase the recall score of the classifier but at the expense of precision. The results shown above may prove useful in guiding the development of the architecture used in the GANs to generate synthetic COVID data and to over sample the minority of the classes within the various data sets I plan on using to train the classifier.

Through this research the researchers found that when dealing with very unbalanced test sets the GAN outperformed both SMOTE and ADASYN when it came to accuracy and precision but had an overall lower recall score. Depending on the context of the problem domain accuracy and precision may be preferred over recall or recall may be preferred over accuracy and precision.

When developing the GANs for generating synthetic data to train COVID-19 classifier there are questions which will need to be answered when deciding to use SMOTE and ADASYN over a traditional GAN architecture. A higher accuracy and precision would be useful in diagnosing COVID-19 in all patients while reducing the risk of unnecessary quarantining due to false positives. However, a higher recall would yield a higher overall identification of COVID positive patients but at the expense of precision, this would help to reduce the transmission of the virus but at the expense of causing unnecessary quarantines of patients.

There are a few limitations the researchers of this paper address in the conclusion section. The research was conducted using only three data sets it is unclear if the results found in the paper will be similar when utilizing other data sets. There are also many other considerations to take into account when using GANs such as mislabelled data, the size of the data set amongst other factors which may influence the creation of the synthetic data.

In another paper entitled "Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation" [36] researchers decided to use a convolutional neural network to detect defects in harvested Lychee fruit. The data set used was then augmented with synthetic data generated with a GAN. To train the classifier and the GAN researchers created a data set of 3743 samples which were divided into 3 categories: mature, defects and rot. The data set created by the researchers suffered from an imbalance much like the data set in the paper previously discussed[33]. To address the imbalance within the data set the researchers used a transformer based GAN to augment the data and create a more diverse and balanced data set which was used to train the classifier to classify the lychee fruit. The researchers created three deep convolutional neural network models to which included SSD-MobileNet V2, Faster RCNN-ResNet50, and Faster RCNN-Inception-ResNet V2. The models were trained with different settings to evaluate and contrast their performance. The researchers found from the evaluations of the models that the data-augmentation did in fact increase the performance of the classifiers.

There is a much need for automation within this particular domain as human fatigue can af-

fect the classification of lychee fruit and incorrect classification of lychee is costly to businesses both in monetary terms and in terms of reputation. This problem domain within Artificial Intelligence has been extensively studied, commonly used methods for detecting defects within fruit are: region growing method, minimum outer rectangle method, threshold segmentation, edge detection,k-mean clustering, and contour finding[36]. Recent progress made in the field of deep learning have demonstrated superior results in a wide range of computer vision tasks among other tasks. Through the use of a DCNN the researchers hope to show superior performance in comparison to traditional machine learning methods currently in use.

The researchers decided to use black leaf lychee samples purchased in two batches from Jiangbei fruit wholesale market in Huzhou city which is located in Guangdong, China when comprising the data set. The first batch contained 2042 mature lychees, which contained 1216 sample which had cracks but had no signs of rot. To gather rot samples for the data set the researchers placed 625 cracked lychee samples in a dry environment at room temperature so they rotted naturally. 495 samples were exposed to sunlight until dry and rotted. The second batch contained 865 lychees that were used as a test sample. The two batches were then placed in foam boxes with ice packs for freshness and shipped back to the researchers lab to maintain the fruits freshness. Data diversity was accomplished by gathering lychee images at six locations in Huizhou College at various times, the images were also taken from different angles. A total of 5014 images were collected for the data set by the researchers.

When training the neural network the researchers used data-augmentation to reduce the risk of overfitting the model and to improve generalisation. The training set was augmented with synthetic data generated by the GAN below is a table of the distribution of categories from the original data set which the researchers were using to train the model.

Category	Original	Original Percentage	Training	Test	Generated	Augmented Training set
Mature	1648	44.03%	1298	350	102	1400
Defects	964	25.75%	700	164	600	1400
Rot	1331	30.22%	896	235	504	1400
Total	3743	100.00%	2994	749	1206	4200

Table 2.8: Comparison of distribution of data augmented vs original(Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

As shown in the table above the augmented data offers a much more balanced data set with all classes of Lychee being represented in equal proportion. Classifiers trained on the original data set may have possibly created a model which would create a high bias for the most represented class of Lychee in the data set.

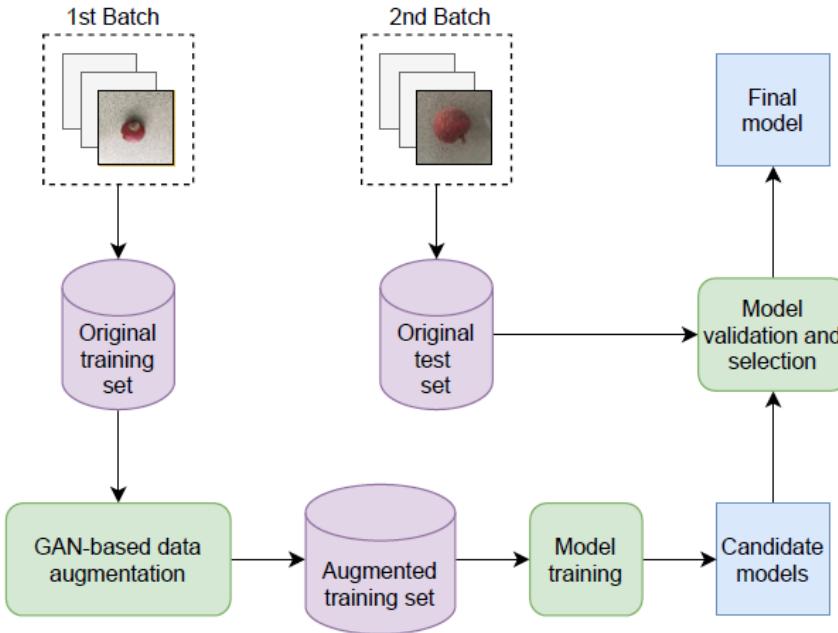


Figure 2.10: Figure of learning framework for Lychee Classification Model[36]

The image above shows the researchers overall configuration of the learning framework for the Lychee surface defect detection model. The original training set was used to train the GAN and from the newly augmented training set the DCNN models were trained to detect defects. The DCNN models were then validated on a test set to compare each models performance.

In this paper the researchers decided to use a variation of GAN known as TransGAN. This version of a GAN is based on purely transformers without the use of convolutions. This version of a GAN consists of a transformer encoder which is made up of a multi-head self-attention module stacked by a feed forward multilayer perceptron. This version of a GAN has traditionally been used for Natural Language Processing but has also found applications in computer vision. In this version of a GAN both the generator  $G$  and discriminator  $D$  are created using transformer encoder blocks. TransGAN has a multi-stage mechanism which will progressively upscale and downscale the image resolution to prevent excessive memory consumption. There is also a grid self-attention module which is developed to the first partition, this is used to reduce the computational load. TransGAN has shown superior results in generative modelling and hence was adopted by the researchers.[36][37]

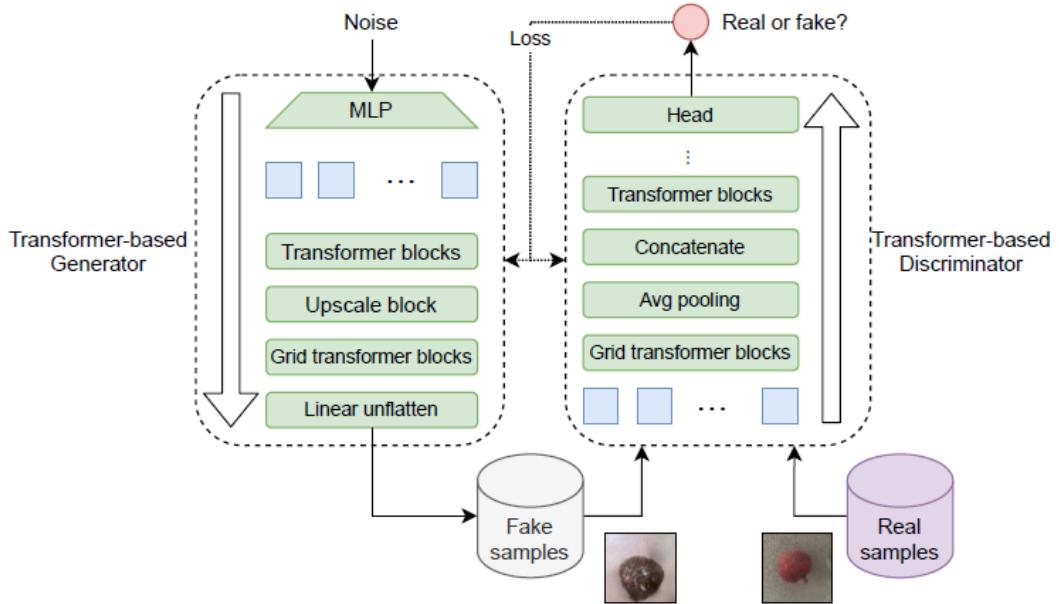


Figure 2.11: Figure of TransGAN (Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

There are a variety of DCNNs used in this paper, I will show diagrams used by the researchers and explain each before further investigating the results of this paper as it's important to understand how each DCNN functions and compare each model's advantages and disadvantages.

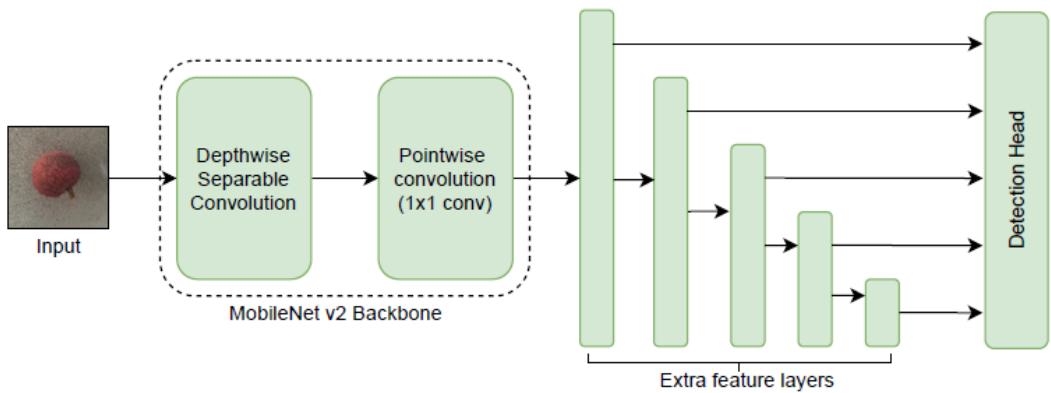


Figure 2.12: Figure of SSD-MobileNet V2 Architecture (Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

The image above shows an example of an SSD-MobileNet V2 DCNN as shown the input goes through a depthwise separable convolution and a pointwise convolution. The goal of SSD is

to perform object localization and classification in a single forward pass of the network. SSD uses multi-scale feature mapping which allows the neural network to simulate the process of the human eye when detecting and classifying objects. MobileNet is a lightweight deep neural network which has proven to be efficient at performing a number of tasks. The model consists of two hyper-parameters a width multiplier and a resolution multiplier, these hyperparameters can be tuned to yield a higher latency or a higher accuracy for speed. Batch Normalization and a ReLU activation function are added after each convolutional layer. The original version of the MobileNet (V1) consisted of an input layer, 13 convolutional layers, an average pooling layer and a fully connected layer[36]. In MobileNetV2 two new features were added, a linear bottleneck between layers and a shortcut connection between bottlenecks which allowed for more efficient training.

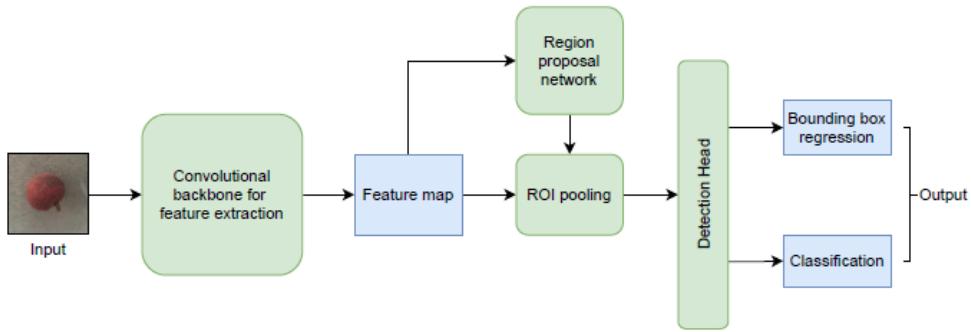


Figure 2.13: Figure of Faster RCNN Architecture (Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

The image above shows the architecture of an RCNN-ResNet50 DCNN, this model was originally proposed by Girshick et al in a 2014 paper entitled "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation"[38]. This proposed DCNN model performs a selective search and extracts 2000 regions from a given image, the regions extracted are called region proposals. Candidate region proposals are warped into a square and then input into a CNN that generates a 4096 dimensional feature vector, this feature vector is then passed to a support vector machine for classification. This model is not suited for real time detection as the researchers found it took approximately 47 seconds to classify a single image, if using this architecture in the COVID-19 diagnostics CNN model there might possibly be a trade-off in terms of time and accuracy. Due to the long time taken to classify an image the researchers proposed a new architecture aptly termed "Faster RCNN" which would eliminate the selective search and instead input the entire image into the CNN to produce the convolutional feature map. This architecture does not have to process 2000 proposals every time it classifies an image which reduces the amount of time taken by the model to classify the image.

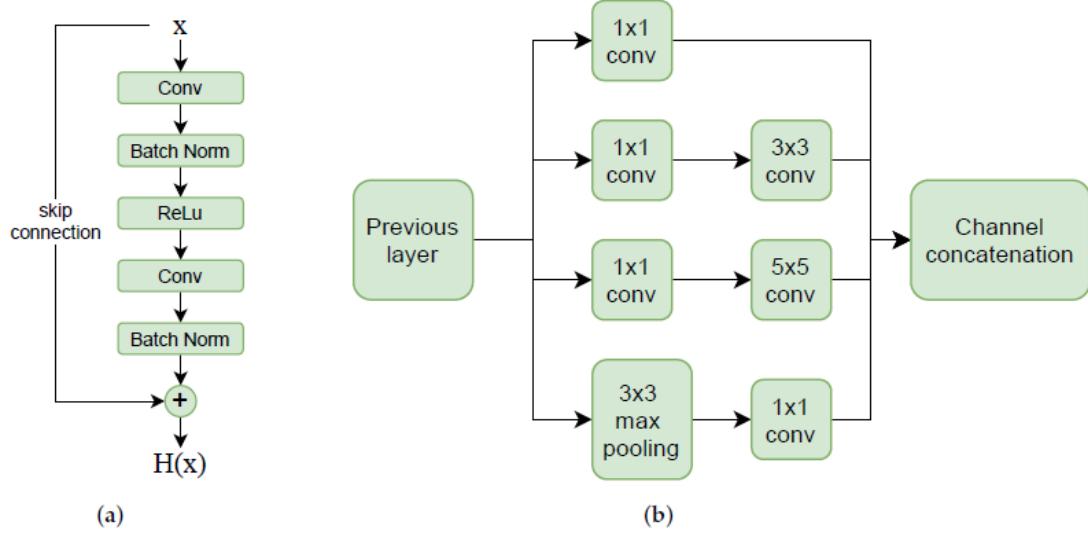


Figure 2.14: Figure of Faster RCNN Res Block and Inception Module (a) Res block; (b) Inception Module. (Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

The final model proposed by the researchers aims at including an inception model to offer superior local topology for the neural network. The module b which is shown in the above image performs multiple convolutional operations on the image input to the model in parallel and combines all the results into a deep feature map. The model uses different filters to perform convolution operations on the input and obtains different information about the image. Processing all the operations in parallel and combining the feature maps allows for a much better image representation.

The researchers used the following configuration to train the TransGAN to generate synthetic data

- Learning rate of  $1 * 10^{-4}$
- Adam as an optimizer
- batch size of 64 for both the generator and discriminator models
- The training ran for 220 epochs

The DCNNs were then trained on both the original and augmented training sets, training 6 different models in total. Each trained model took an image as input and output a box for each detected Lychee with a predicted category along with a confidence score. The hyper parameter settings for each model were as follows:

- Weight decay of  $5 * 10^{-4}$

- Momentum of  $8 * 10^{-1}$
- Verification Period of 5000
- Batch Size of 32
- Learning Rate of  $5 * 10^{-3}$
- And ran for a total of 1500 epochs

The results before augmentation for the models were as follows:

- SSD-MobileNet V2: 88.95%
- Faster RCNN-ResNet50: 91.57%
- Faster RCNN-Inception ResNet V2: 91.25%

The researchers found that training on the GAN-augmented data that the performance increased by the following amounts for each of the models.

- SSD-MobileNet V2: 2.86%
- Faster RCNN-ResNet50: 1%
- Faster RCNN-Inception ResNet V2: 0.58%

As we can see from the above list SSD-MobileNet V2 had the most gains in terms of performance. Due to the large imbalance between classes in the dataset the performance gap is quite large. The mean average precision before augmentation was as follows:

- SSD-MobileNet V2: 9.45%
- Faster RCNN-ResNet50: 6.12%
- Faster RCNN-Inception ResNet V2: 7.77%

After the augmentation process the researchers found that the values were reduced for each of the three models by the following values:

- SSD-MobileNet V2: 1.78%
- Faster RCNN-ResNet50: 4.45%
- Faster RCNN-Inception ResNet V2: 2.35%

As we can see from the above values the augmentation process yielded better quality models that can better differentiate between the three classes of fruit (rotten, defective, and mature). The model which has shown the most improvement in terms of mean average precision was Faster RCNN-ResNet50, however the researchers found that Faster RCNN-Inception-ResNet V2 was the most accurate on detecting rotten samples.

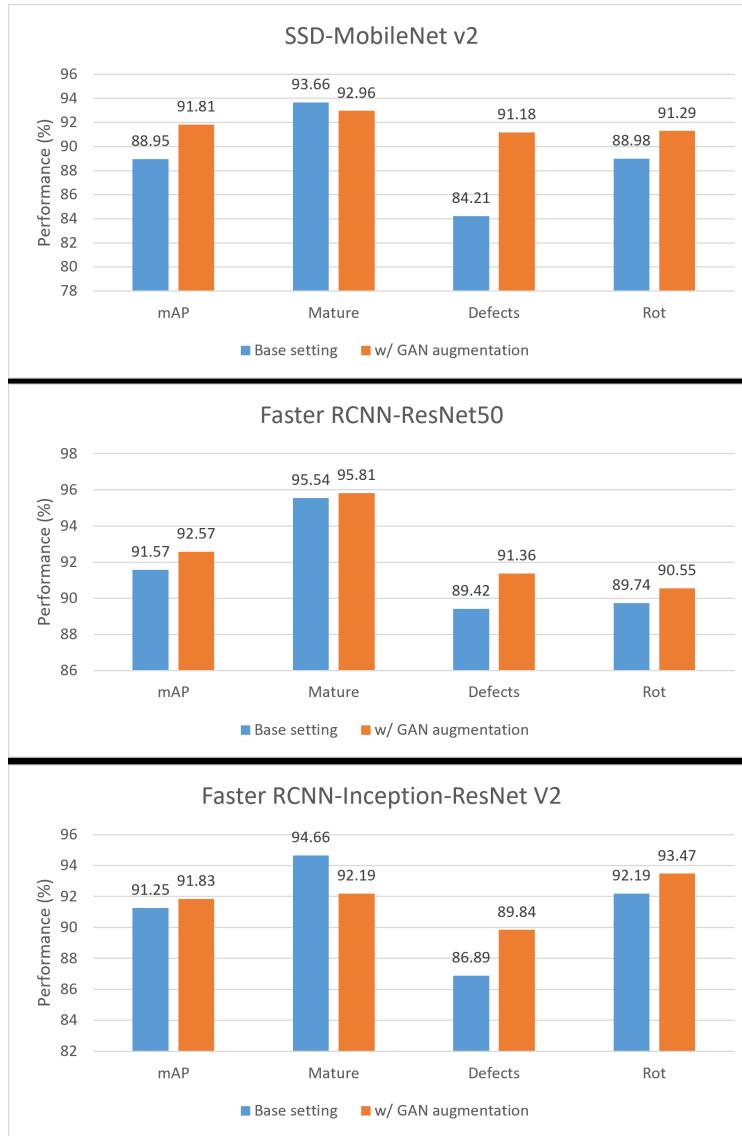


Figure 2.15: Figure of Mean Average Precision of Models. (Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

Given that detecting defects in Lychee is a time-sensitive job the researchers compared each of the three models in terms of detection speed. This would also be a factor when developing the diagnostic models for detecting COVID-19 as the sooner the virus can be detected the sooner it can be treated effectively.

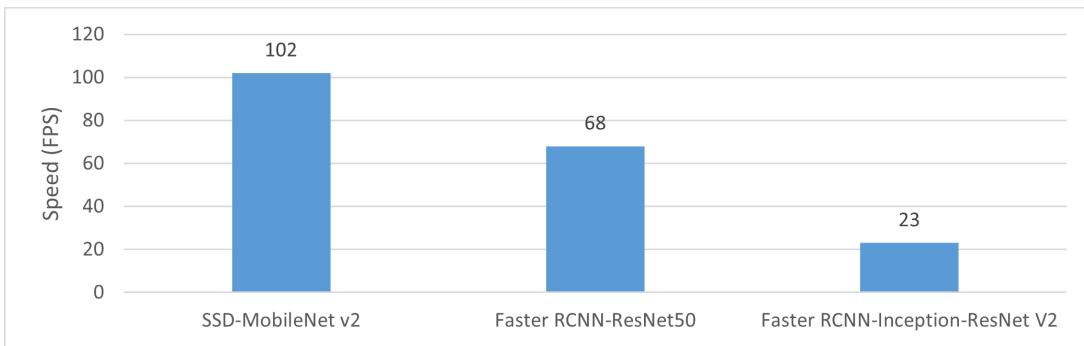


Figure 2.16: Figure of Speed of Models in classifying Lychee. (Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

As we can see above SSD-MobileNet V2 classifies the Lychee faster than the other two models although all 3 models met the researchers requirement for Lychee defect detection. These results are of particular interest and may prove useful when designing the automated diagnosis tool for COVID-19. SSD-MobileNet V2 could perhaps diagnose the patients faster than the medical professionals analyzing the patient, thus freeing up time for medical professionals to assist other patients.

I will list the accuracy of each of the models with and without data augmentation below to compare and contrast the classification performance.

Model	Setting	Acc	Rec	Spe	F1
SSD-MobileNet V2	Base setting	89.81%	90.08%	89.89%	89.46%
SSD-MobileNet V2	GAN Augmentation	91.96%	92.06%	91.99%	91.92%
Faster RCNN-ResNet50.50	Base Setting	91.82%	92.23%	91.95%	91.72%
Faster RCNN-ResNet50.50	GAN Augmentation	92.76%	92.96%	92.80%	92.55%
Faster RCNN-Inception-ResNet V2	Base Setting	91.96%	92.07%	91.98%	91.54%
Faster RCNN-Inception-ResNet V2	GAN Augmentation	92.36%	91.74%	92.22%	91.86%

Table 2.9: Comparison of accuracy of base models vs models with data-augmentation(Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[36]

As shown in the above table all of the models had better accuracy, recall(with the exception of Faster RCNN Inception model), specificity and F1 score with the data augmented data set. This shows that the classifiers were more accurate when classifying the fruit when they were trained on a more balanced data set.

## 2.5 Conclusion

From analyzing existing models for the automated detection of COVID-19 it appears that data quality and data shortage are key areas where improvements could be made to improve the overall accuracy and usability of the existing models. From the analysis of the current paradigms in convolutional neural network and data augmentation of this thesis it is clearly shown that data-augmentation has proven very useful in a wide-range of applications which range from detecting defects in Lychee to identifying credit card fraud. Given the positive results shown in the given problem domains it seems a reasonable conjecture that the use of data-augmentation would also prove useful for COVID-19 detection. In the next sections of this thesis I will discuss the implementation methods used when creating both the convolutional models and the data-augmentation models, the results of the models implemented and further research which could be conducted into this area. It will be interesting to see if the findings of the papers explored above are transferable to this new problem domain.

# **Chapter 3**

## **Implementation**

### **3.1 Libraries Used**

### **3.2 GAN Architectures**

### **3.3 CNN Design**

## **Chapter 4**

# **Results of Research and Conclusions**

## **Chapter 5**

# **Future Work and Research**

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