

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

**This report was written as part of a Masters of Science in Artificial Intelligence and Big Data Analytics*

Ultan Kearns
*Department of Computing
ATU Letterkenny*

I. ABSTRACT

This report was written as a requirement for a Masters of Science in Artificial Intelligence and Big Data Analytics at ATU Letterkenny and aims to summarize the results of the research into synthetic data generation to train CNNs for the purpose of automated detection of COVID-19. The limited amount of data available for training CNNs to recognize COVID-positive and COVID-negative patients has led to a number of researchers training their models on mislabelled or imbalanced datasets, the results of this research have shown that there is some promise to synthetically augmenting data through the use of generative deep-learning. Throughout the research we used a variety of different methods to generate the new synthetic data and to balance the dataset by augmenting minority classes to bring them in balance with the majority classes. The results of this research have shown that the use of synthetic augmentation can improve the accuracy of some CNN models and although the CNN models were unable to surpass the currently achieved validation set accuracy of the COVID models mentioned in the literature review (the majority of these models attained a validation set accuracy of > 98%)[1][2] it is worth noting that the top model (Extensive CNN CT EfficientNetV2S) trained achieved a test set accuracy of 96% when trained on a larger dataset which contained 4,655 more images than the model mentioned in the literature review. It is also worth noting that this research was conducted using a test set whereas the model mentioned in the literature review only used a validation set which shows that the researchers may have overfit the validation set.

II. INTRODUCTION

The crux of the research conducted centred around the question "can generative deep-learning be used to improve the results of currently existing models used to automate the diagnosis of COVID-19?" When beginning the study we researched various different architectures of GAN and various architectures of CNNs. The main GAN architecture used in this study is the Deep Convolutional GAN, this was the GAN which had the most success in generating synthetic images. In addition to the DCGAN Variational Autoencoders (VAEs)

were also used but had limited success when augmenting the datasets. Transfer learning was also used with a number of different pre-trained models all trained using the ImageNet dataset being used to automate COVID-19 diagnosis and many were able to outperform the baseline models. The research goal was achieved upon conclusion of this thesis with many of the models trained on the augmented datasets outperforming the models trained on the non-augmented datasets.

The research conducted used a number of datasets to train both the CNNs and the GANs. Three datasets were used to train the GAN models these were the COVID-19 Radiography Dataset, the Extensive COVID-19 dataset, and finally the COVID-19 X-Ray dataset. There was also a fourth dataset used to train CNN models the COVID-19 Chest X-Ray dataset. However this dataset was not suitable to train GAN models as there are 11 classes and some classes are extremely underrepresented so in an effort to conserve resources the decision was made not to use this dataset when training GANs. The CNN models for this dataset were still included as the effect of transfer-learning was still interesting to see when using a severely limited dataset.

III. LITERATURE REVIEW FINDINGS

A number of papers were reviewed during the course of this research to determine current paradigms in generative deep-learning and computer vision. This section began with researching and analysing currently existing models which were used in the automated detection of COVID-19 in patients. In a paper by Mahmoudi, Benamour et al[2] researchers investigated deep learning approaches to aid in the creation of an automated diagnostic tool using computed topography scans. The researchers found that segmenting the infected region of the patients scan and using a technique called Contrast Limited Adaptive Histogram Equalization was beneficial to creating a homogenous dataset and aiding in the improvement of the model's performance. The researchers removed black slices from the images so that only the region of interest was shown and used a U-net architecture for more timely and accurate segmentation of images. Four-fold cross-validation was also used in the training of this model. The model achieved an accuracy of 98% when diagnosing patients. Despite the high

accuracy the model suffered from lack of data as only 20 CT Scans were used to train and validate the model(40 images in total). The model was also deprived of a test set which may have inflated the accuracy as it is highly likely the model was overfitting to the validation set. Due to the lack of data and the high-cost associated with data-collection the researchers were unable to collect more data for a test-set to provide a less biased and more objective result.

There is also a high potential for bias in this study as the limited amount of data and possibly mislabelled or misclassified data may have had an adverse effect on analyzing the results. This links back to a term "Frankenstein Datasets" these are datasets which are mislabelled, suffer from lack of data-quality, biased, and spliced together from different sources. Frankenstein datasets were used initially in the early-stages of the pandemic as many researchers and companies rushed to find a solution to training a high quality automated COVID-19 diagnostic tool to alleviate the heavy burden placed upon medical staff at the time.

The issue with limited data and imbalance between classes within the datasets is shown in the next study analyzed also and seems to be a recurring theme when analyzing currently existing automated COVID-19 diagnostic tools. In a paper by Islam, Islam, and Asraf[1] a new method was used to automate the diagnosis of COVID-19 called LSTM(Long Short Term Memory). The model trained as part of this research used a much larger dataset than the study analyzed previously[2], the dataset used contained 4,575 X-ray images in total with 1,525 images being COVID-19 Positive. The model achieved an area under curve accuracy of 99.4%, an accuracy of 99%, a specificity of 99.2%, and a sensitivity of 99.3%. The researchers suggest that the study may have been improved if more data was available to them, the lack of data is clearly visible from the size of the dataset and the imbalance between classes. The model does appear to improve upon the initial model mentioned in the previous study[2] as it is trained on a far larger dataset and would have an increased ability to generalize. As shown when comparing the accuracy of this model with the one mentioned previously this model has a much higher accuracy.

The model trained as part of this study appeared to greatly benefit from the use of an LSTM architecture. The use of which allows the neural network to remember and carry previously learned information to layers deeper in the network, this greatly helps with the problems of vanishing and exploding gradients[3].

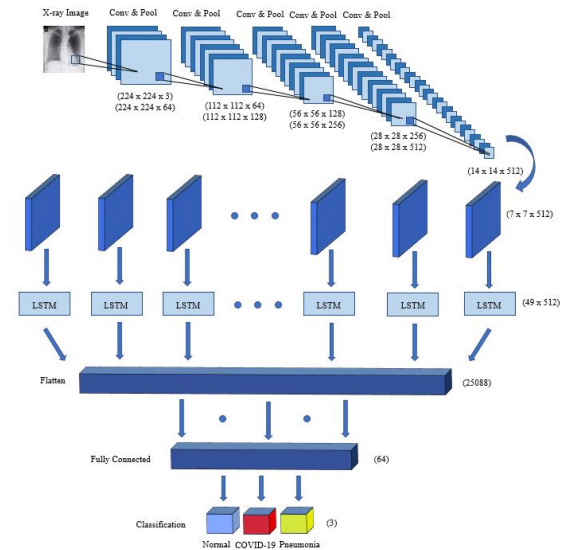


Fig. 1: Overview of a Typical LSTM Network[1]

Figure 1 shows the architecture of an LSTM Network as shown above the LSTM is comprised of four main gates an input gate, "a forget gate", an update gate, and finally an output gate. The gates essentially determine which data the model should remember and which data isn't useful for training and can be forgotten. The models trained achieved a much better result than the model in the previous study and when considering the much larger size of the dataset the model trained as part of this study would have a much higher accuracy when it came to generalizing and classifying new data.

In the literature review we also address the challenges and limitations of using Artificial Intelligence in developing automated diagnosis systems for COVID-19 classification. In a paper by Huang, Yang and others[4], researchers discuss the current challenges and limitations of developing an Artificial Intelligence model to assist medical professionals in the identification and diagnosis of COVID-19. The challenges include: lack of data, lack of data quality, and the use of poorly merged data sets which we discussed earlier("Frankenstein datasets"). There are more challenges other than those previously discussed such as finding patients who are COVID-19 positive and asymptomatic(most will not seek medical diagnosis as they don't present symptoms), the labelling of data is also an issue as there is a risk of mislabelled data by clinicians given moderate signs of COVID-19 being hard to definitively classify as COVID positive or negative. The risk of false positives and false negatives both of which present issues such as unnecessary quarantine and further spread of infection. To mitigate these challenges the researchers of this paper suggest that when developing an AI diagnostic system that developers should combine chest imaging, exposure history, and laboratory tests when training / testing the model. The issue with this approach is laws concerning data-collection and ethical questions regarding the right to the patients privacy. There is also a high cost associated with data-collection and

to collect enough data may take quite a long time.

The issues explored in the literature review regarding current constraints to developing automated diagnostic models for COVID-19 detection lead into the next section Research into Data Augmentation and Convolutional Neural Networks. In this section we aim to analyze the use of augmenting datasets with synthetic data created by GANs to see if there have been positive results across different problem domains. The section opens with an explanation of synthetic data and discussing that there are numerous techniques and methodologies for using data augmentation, for the purpose of this study we will be using GANs to generate new data from currently existing data. Then we move on to discuss some of the advantages of using data augmentation for training the models, the main advantages are: larger training set to train models on, reduces overfitting, helps to prevent underfitting and improve the accuracy of the model, and reduces the cost/time associated with gathering new data, and increases the models ability to generalize. We also discuss the limitations of using GANs the key limitations are: inability to reduce bias(if bias is present in the dataset the synthetic set will also contain bias), hard to generate discrete data(this had little effect on our research), and the data generated will need to be evaluated(some of the synthetic data generated in this study appeared malformed, unfortunately due to the time associated with pruning such data and the computational resource limitations such malformed images are present in the augmented sets).

After discussing the advantages and limitations of using synthetically augmented data we then moved on to discuss a paper by Tanaka and Aranha[5]. In this paper the researchers discuss two algorithms SMOTE(Synthetic Minority Over-sampling Technique) [6]and ADASYN (Adaptive Synthetic Sampling Approach for Imbalanced Learning)[7]. Both techniques are used to oversample the minority class within datasets to balance the dataset.

We then discuss how each algorithm works. SMOTE works by creating artificial data which takes into account the data's position, a random point in the least represented class in the dataset is selected and SMOTE identifies members of the same class within the data by using the k-nearest neighbour algorithm which is a form of unsupervised learning. SMOTE then generates an entirely new point in the vector for each pair which is situated between the two pieces of data, the new point is then positioned at a random percentage away from the initial point chosen[5]. ADASYN works in a similar way to SMOTE and was originally based on SMOTE. Both 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 that ADASYN adds helps to increase the amount of variance within the synthetic data. We then evaluate the performance of each of these algorithms. When testing both SMOTE and ADASYN the researchers found that both underperformed in accuracy on the imbalanced dataset compared to the original model but had a higher recall. When the datasets were balanced it was found that SMOTE and ADASYN performed much better. The models

also achieved an increase in accuracy and performance when trained using traditional GANs. By reviewing this study it showed that the use of GANs were able to improve accuracy of certain classification models across a number of problem domains. The researchers used 3 datasets when training the models and synthetically augmenting the datasets. These datasets were

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

Given that the researchers had shown success in using GANs across these vastly different problem domains it showed that there may be some value into researching syntehtic data augmentation when it came to alleviating data-shortages in COVID-19 diagnosis.

The next study analyzed as part of researching the current use of GANs to augment imbalanced datasets was from a paper by Wang and Xiao[8]. In this paper the use of convolutional neural networks was employed to discern defective lychee. The dataset used was augmented using a generative adversarial network to solve the issues of imbalance between classes in the dataset used. The researchers also used a variety of CNN architectures which included: SSD-MobileNet V2, Faster RCNN-ResNet50, and Faster RCNN-Inception-ResNet V2. The models used were trained with different hyperparameters to evaluate their performance. Through the use of GANs the researchers were able to increase the mean average precision for each of the following architectures: SSD-MobileNet V2 2.86%Faster RCNN-ResNet50 V2 1% Faster RCNN-Inception-ResNet V2 0.58%. The mean average precision gap was also greatly reduced through the use an augmented dataset which can be seen in tableI.

Name of Model	Mean Average Precision Performance Gap
SSD-MobileNet V2	1.78%
Faster RCNN-ResNet50 V2	4.45%
Faster RCNN-Inception-ResNet V2	2.35%

TABLE I: Mean average precision after Augmentation(lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation)[8]

When evaluating the performance of the models the researchers found that GAN augmentation had increased the accuracy of a number of models as shown in table II

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	Base Setting	91.82%	92.23%	91.95%	91.72%
Faster RCNN-ResNet50	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 II: 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)[8]

From the studies analyzed in the literature review it is clear to see that data-augmentation has achieved promising results

in certain problem domains. Through the literature review we gained a perspective and insight into how to go about balancing imbalanced datasets when it came to augmenting COVID-19 X-rays and CT Scans. The literature review revealed key issues with current automated diagnostic models for COVID-19 and also showed that through the use of GANs we could solve some of the issues affecting current models.

IV. DESIGN & IMPLEMENTATION

When starting off the research we decided it would be best to include baseline CNN models which we would use as a metric when evaluating the performance of the augmented models. The baseline models used a train / validation / test split of 70% for training, 10% for validation and 20% for test. The reasoning for this is that a large amount should be used for training as the model would need to be exposed to many features in the data. The validation split was important to determine if the model was performing well during training. The test set size was double the validation size so that when gauging the model's performance the test set would have more variety and could measure the model's ability to generalize better. The use of transfer-learning was also employed when implementing the CNNs three additional models were created for each dataset we used the following CNN architectures: Xception, ResnetModel50V2, and EfficientNetV2S. Each of these architectures were trained on the ImageNet dataset, the ImageNet dataset is comprised of 14,197,122 images and contains 1,000 classes[9]. Each of these pre-trained models also had an additional 2 layers appended onto them, one layer to train and another layer which was the output layer used for classification.

After achieving satisfactory results on these baseline models we then set to work upon researching and creating the GAN models. The DCGAN models were created based off of an example from the Keras website[10]. The models were run a number of times with hyperparameters being adjusted to improve the models performance. The output from these models was then reviewed, the output of the model was stored on Google Drive. After sifting through the images and comparing and contrasting them to real samples selected from the dataset it was clear that the models were in fact producing a similar output to the real samples in the dataset.



(a) Real COVID-19 Radiography Mask Example



(b) Generated COVID-19 Radiography Mask Example DCGAN

As shown in the above images 2a and 2b the real and synthetic example share a striking resemblance. There were however a few issues with the results produced from the GANs. There were a number of malformed images, some which had artefacts which can be seen in figure and figure

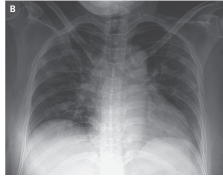


(a) Synthetically generated COVID 19 mask with Artefacts(DCGAN)



(b) Malformed Image of synthetically generated COVID 19 Mask(DCGAN)

As shown in the figures above the synthetically generated example 4a lacks the quality of the original 4b but appears to have similar features. The next figures show an example of a synthetically generated pneumonia X-ray along with a sample taken from the dataset



(a) Real Pneumonia X-ray Dataset COVID-19



(b) Synthetically Generated Pneumonia X-ray Dataset COVID-19 DCGAN

These issues occurred across the datasets and affected all the images produced by the GAN regardless of if the images were X-rays or CT scans. Some of the images produced by the GANs also appeared slightly grainy or lacking in quality compared to those in the dataset. This issue may have been caused due to the downscaling in resolution as due to computational limitations the images produced by the GANs in this study have a resolution of 128×128 . The amount of malformed issues may have been greatly reduced by increasing the resolution of the images output by the GANs and standardising the images input into the GANs (a number of datasets used in this study did not have a standardised resolution for images).

The use of VAEs was also employed for this study but they did not seem to produce satisfactory results most of the images produced by the VAEs appeared to be the exact same image, which leads us to believe the VAE suffered from mode collapse.

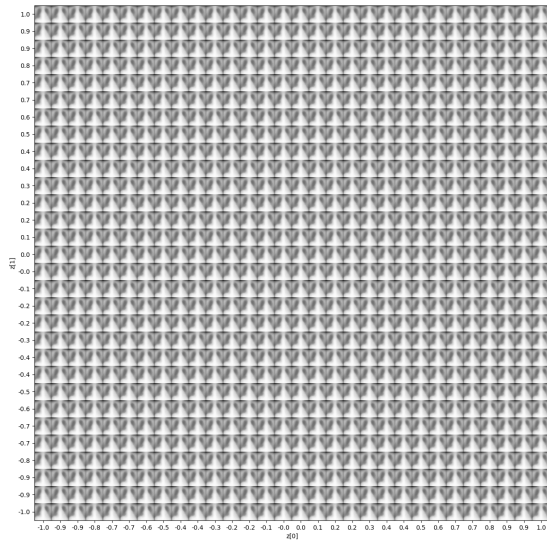


Fig. 5: Example of VAE mode collapse

Multiple VAEs were trained some appeared to have suffered from mode collapse and others produced no output at all. There may have been some use to the images produced by the VAE but to the untrained eye each image produced looks the same.

Once the GANs were trained the discriminator and generator models were then loaded and were run for as many epochs as it would take to produce the number of images required. Due to computational limits and the need to make the imbalance between classes as small as possible the GAN produced 10 images per epoch and brought the classes into relative balance with each other, the minority classes may be slightly underrepresented by a small amount of 1 - 9 images.

The images were then saved to Google Drive and were used to augment the different datasets by moving the produced images into the target dataset. Once this was done the original baseline CNNs were replicated and the data reloaded and split so that our new data would be used in the training and testing of the models. The train / validation / test split was kept the same so as to obtain objective results.

Once the new models were trained and their performance documented we then moved on to comparing and contrasting the results with those of the baseline models.

V. RESULTS

Overall a number of augmented models showed improvements in terms of both accuracy and loss. This means that the augmented models performed better than the original models. The increase in performance of the augmented models may provide advantages in this area and allow for doctors to more easily diagnose patients more accurately, which would in turn allow doctors to have more free-time to spend on other patients. The results from this study could possibly be used in a number of fields and different areas other than the automated diagnosis of COVID-19 but more research will need to be done to gauge synthetically generated data in said areas and fields.

In comparison to the existing COVID automated diagnosis model viewed in the literature review which had accuracy of 99.4% on a validation none of the augmented or original models were able to surpass this performance on the validation, but it is worth noting that the models mentioned in the literature review could be overfitting the validation set. The model which came closest to the accuracy attained by the models mentioned in the literature review was the augmented Extensive CNN CT EfficientNetV2S model which had a test set accuracy of 0.9697 or approximately 97%. When evaluating the performance it is important to remember that the size of the dataset plays a significant role, the literature review model was trained on a dataset with of 4,575 X-ray images, 1,525 of which were X-rays of COVID positive patients. In comparison the Extensive COVID-19 CT dataset contains 2,628 Non-COVID CT scans and 5,427 COVID CT scans, the augmented dataset contained an additional 2,700 Non-COVID images which in total gives the dataset a size of 10,755 images which is an increase of 4,655 images.

Given that the model is exposed to more data it could be argued that this model would be more beneficial in a clinical setting given it is exposed to more features in the data which could be an improvement in terms of the model's ability to generalize. The augmented radiography models also showed some decent performance compared to the model mentioned in the literature review with the top model getting a test set accuracy of 0.9604 or 96% when trained on a far larger dataset of 60,933 images. Some of the non-augmented models were also able to get close to the COVID-19 diagnostic model mentioned in the literature review while training on slightly larger datasets the Extensive COVID-19 X-ray model which had a test set accuracy of 0.9766 or approximately 98% is a good example of this.

The overall results of this study found that synthetic data was useful for some model architectures and improved a number of models but a number of models trained on the synthetic data performed poorly compared to models trained on real data. It appears more research is needed in this area as computational limitations and lack of data pruning may have skewed the results negatively. The variation of data also proved to be detrimental in some datasets which can be seen from the Extensive COVID-19 X-ray CNN models, the poor performance could be due to the variety of data present as some of the X-rays are taken from the side and others are taken from with the patient facing the camera.

We can see from the figures produced by the GANs that the models were able to reproduce convincing images which look close to their target domain. We can also see that some images such as figures 3a and 3b have aberrations and artifacts which distort the image and could confuse the model when training on the synthetic data. The only solution to this issue would be to prune each image manually which would take a lot of time and effort. Due to time constraints we were unable to prune and curate each image. The models could possibly be improved by removing malformed images or images with artifacts. There is also the issue of image resolution which may have caused some models to perform worse than they normally would have if the images were standardized. Due to computational limitations it was very difficult and time-consuming to train GANs to produce high resolution images. Trying to produce images with high resolutions used a lot of computational power and often caused Colab to crash during training. However, the augmented CNN models do show improvement on a number of datasets such as the Radiography and Extensive CT datasets. Although the accuracy may be lower and the loss may be higher for some models the added data may be beneficial when applied in a clinical setting, as the augmented dataset adds more variety of images and more data to for the model to learn from to detect subtle features and characteristics. It is important to remember the size of the datasets when gauging these models as it would be easier to achieve a much higher accuracy and lower loss on smaller datasets than it would on larger sets.

VI. CONCLUSION

In conclusion despite the computational resource / financial limitations and numerous other limitations faced throughout the course of this study a number of models showed significant improvement in terms of both accuracy and loss when the data was augmented. Although none of the original or augmented models outperformed the accuracy seen in the models evaluated in the literature review it is worth noting that the models did achieve a high test set accuracy, the models in the literature review were not evaluated using a test set and may have overfitted to the validation set.

The results of this study are significant in that they show that through the use of synthetic data-augmentation the overall performance of models could be improved in this problem domain. The model's ability to generalize is very important in the diagnosis of COVID-19 as it can help medical professionals prevent the spread of COVID-19 and would help reduce the risk of unnecessarily quarantining patients who were incorrectly diagnosed as COVID positive.

The conclusion of this research shows that there is much more work to be done in this problem domain. To truly evaluate the models included in this study they would have to be deployed and evaluated in a clinical setting so their usefulness can be assessed by medical professionals. There are numerous improvements which could be made to this study such as those mentioned earlier in this paper. The overall objective of the research was achieved and the usefulness of synthetic data has been proven by evaluating the results of the baseline models with the results of the augmented models.

Although there are many more improvements which could be made to this study the results show that the balancing of classes through the use of generative deep-learning can produce propitious results and more research into this area is needed.

REFERENCES

- [1] I. Islam and Asraf, "A Combined Deep CNN-LSTM Network for the Detection of Novel Coronavirus (COVID-19) using X-ray Images," *Informatics in Medicine Unlocked*, 2020. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2352914820305621>.
- [2] B. Mahmoudi *et al.*, "A Deep Learning-Based Diagnosis System for COVID-19 Detection and Pneumonia Screening Using CT Imaging," *Applied Sciences*, 2022. [Online]. Available: <https://www.mdpi.com/2076-3417/12/10/4825/>.
- [3] S. Hochreiter, "The Vanishing Gradient Problem During Learning Recurrent Neural Nets and Problem Solutions," *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, vol. 06, no. 02, pp. 107–116, 1998. [Online]. Available: <https://doi.org/10.1142/S0218488598000094>.
- [4] Y. Huang *et al.*, "Artificial Intelligence in The Diagnosis of COVID-19 Challenges and Perspectives," *International Journal of Biological Sciences*, pp. 1–7, 2021. [Online]. Available: <https://pubmed.ncbi.nlm.nih.gov/33907522/>.
- [5] Tanaka and Aranha, "Data Augmentation Using GANs," *Proceedings of Machine Learning Research*, pp. 1–16, 2019. [Online]. Available: <https://arxiv.org/pdf/1904.09135.pdf>.
- [6] K. W. Bowyer, N. V. Chawla, L. O. Hall, and W. P. Kegelmeyer, "SMOTE: synthetic minority over-sampling technique," *CoRR*, vol. abs/1106.1813, 2011. arXiv: 1106.1813. [Online]. Available: <http://arxiv.org/abs/1106.1813>.
- [7] G. He Bai, "ADASYN: Adaptive Synthetic Sampling Approach for Imbalanced Learning," *IEEE World Congress on Computational Intelligence*, pp. 1322–1328, 2008. [Online]. Available: https://www.researchgate.net/publication/224330873_ADASYN_Adaptive_Synthetic_Sampling_Approach_for_Imbalanced_Learning.
- [8] Wang and Xiao, "Lychee Surface Defect Detection Based on Deep Convolutional Neural Networks with GAN-Based Data Augmentation," *Agronomy*, vol. 11, 2021. [Online]. Available: <https://www.mdpi.com/2073-4395/11/8/1500>.
- [9] Multiple, "ImageNet," [Online]. Available: <https://www.image-net.org/index.php/>.
- [10] F. Chollet, "DCGAN to Generate Face Images," [Online]. Available: https://keras.io/examples/generative/dcgan_overriding_train_step/.