Improving the model architecture could further boost prediction accuracy. Combining CNN feature extraction with Random Forest or Gradient Boosting, hybrid learning methods could offer more stable predictions. Adopting architectures like EfficientNet or Vision Transformers may enhance feature abstraction for diverse environments. Ensemble techniques, such as stacking or bagging, could help mitigate overfitting and improve robustness across varied carbon stock distributions.

IV. Conclusion

This study evaluated the effectiveness of VGG-16 and ResNet-20 in estimating carbon stock using drone imagery, with hyperparameter optimization conducted through Optuna and GridSearchCV. The results demonstrate that VGG-16 consistently outperformed ResNet-20, achieving the highest R^2 score of 0.645 with Optuna, highlighting its superior feature extraction capabilities in this context.

The study highlighted significant challenges, including issues with dataset imbalance and the difficulty in accurately predicting high-carbon stock values, which often leads to systematic underestimation. The findings suggest that addressing these challenges through advanced data augmentation, synthetic data generation, and multispectral or LiDAR data integration can enhance model robustness and generalization.

Future research should investigate hybrid approaches that combine deep learning with traditional machine learning techniques, such as Random Forest and Gradient Boosting, to improve predictive stability. Furthermore, exploring alternative architectures like EfficientNet and Vision Transformers and adopting ensemble learning strategies could enhance accuracy and resilience in varied environmental conditions.

References

[1] Zhi Huang and Brian G. Lees, "Combining Non-Parametric Models for Multisource Predictive Forest Mapping," 2004.

[2] G. Petrokofsky *et al.*, "Comparison of methods for measuring and assessing carbon stocks and changes in terrestrial carbon pools. How do the accuracy and precision of current methods compare? A systematic review protocol," Jun. 21, 2012, *BioMed Central Ltd.* doi: 10.1186/2047-2382-1-6.

[3] G. Gebeyehu, T. Soromessa, T. Bekele, and D. Teketay, "Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia," *J Ecol Environ*, vol. 43, no. 1, Mar. 2019, doi: 10.1186/s41610-019-0105-8.

[4] E. Tanuwijaya and A. Roseanne, "Modifikasi Arsitektur VGG16 untuk Klasifikasi Citra Digital Rempah-Rempah Indonesia," *MATRIK : Jurnal Manajemen, Teknik Informatika dan Rekayasa Komputer*, vol. 21, no. 1, pp. 189–196, Nov. 2021, doi: 10.30812/matrik.v21i1.1492.

[5] T. Bartz-Beielstein, "PyTorch Hyperparameter Tuning - A Tutorial for spotPython," May 2023, [Online]. Available: http://arxiv.org/abs/2305.11930

[6] R. A. Birdsey, D. A. DellaSala, W. S. Walker, S. R. Gorelik, G. Rose, and C. E. Ramírez, "Assessing carbon stocks and accumulation potential of mature forests and larger trees in U.S. federal lands," *Frontiers in Forests and Global Change*, vol. 5, Jan. 2023, doi: 10.3389/ffgc.2022.1074508.

[7] S. Albawi, T. A. Mohammed, and S. Al-Zawi, "Understanding of a convolutional neural network," in *Proceedings of 2017 International Conference on Engineering and Technology, ICET 2017*, Institute of Electrical and Electronics Engineers Inc., Jul. 2017, pp. 1–6. doi: 10.1109/ICEngTechnol.2017.8308186.

[8] I. Made Wismadi, D. Care Khrisne, and I. Made Arsa Suyadnya, "Detecting the Ripeness of Harvest-Ready Dragon Fruit using Smaller VGGNet-Like Network," 2019.

[9] A. J. Fetterman *et al.*, "Tune As You Scale: Hyperparameter Optimization For Compute Efficient Training," Jun. 2023, [Online]. Available: http://arxiv.org/abs/2306.08055

[10] Subhasis Dasgupta Dr., "A COMPARATIVE STUDY OF HYPERPARAMETER TUNING METHODS SUBHASIS DASGUPTA & JAYDIP SEN," Jul. 2024. [Online]. Available: https://www.mlfactor.com/images/var_bias_trade2.png]

[11] C. Szegedy, S. Ioffe, V. Vanhoucke, and A. Alemi, "Inception-v4, Inception-ResNet and the Impact of Residual Connections on Learning."

[12] T. A. T. K. Azaharan, A. K. Mahamad, S. Saon, Muladi, and S. W. Mudjanarko, "Investigation of VGG-16, x and AlexNet Performance for Brain Tumor Detection," *International journal of online and biomedical engineering*, vol. 19, no. 8, pp. 97–109, 2023, doi: 10.3991/ijoe.v19i08.38619.

[13] G. Qi, J. Jiang, Q. Deng, and D. Yang, "Optuna-CNN based proxy model for calculation of perforating shock loads." [Online]. Available: https://ssrn.com/abstract=4752997

[14] T. Akiba, S. Sano, T. Yanase, T. Ohta, and M. Koyama, "Optuna: A Next-generation Hyperparameter Optimization Framework," Jul. 2019, [Online]. Available: http://arxiv.org/abs/1907.10902

[15] S. Towhidul Islam Tonmoy and S. Mehedi Zaman, "OOG-Optuna Optimized GAN Sampling Technique for Tabular Imbalanced Malware Data."

[16] A. Khairul, D. Gusman, and H. Adeswastoto, "Web-Based Waste Reporting Application Analysis in Dinas Lingkungan Hidup Kabupaten Kampar Keywords MYSQL PHP waste reporting application website," *JOURNAL OF ENGINEERING SCIENCE AND TECHNOLOGY MANAGEMENT*, vol. 2, no. 1, pp. 2828–7886, 2022.

[17] A. Tikaningsih, P. Lestari, A. Nurhopipah, I. Tahyudin, E. Winarto, and N. Hassa, "Telematika Optuna Based Hyperparameter Tuning for Improving the Performance Prediction Mortality and Hospital Length of Stay for Stroke Patients," vol. 17, no. 1, pp. 1–16, 2024, doi: 10.35671/telematika.v17i1.2816.

[18] A. Sukma Yogiswara, T. Osawa, I. Wayan Nuarsa, and A. Rahman As-Shakur, "Carbon Stocks Estimation on Urban Vegetation Using UAV.., [Agus Sukma Yogiswara, dkk] CARBON STOCKS ESTIMATION ON URBAN VEGETATION USING UAV-SfM PHOTOGRAMMETRY METHOD".

[19] A. Mumuni and F. Mumuni, "Data augmentation: A comprehensive survey of modern approaches," Dec. 01, 2022, *Elsevier B.V.* doi: 10.1016/j.array.2022.100258.

[20] K. Simonyan and A. Zisserman, "Very Deep Convolutional Networks for Large-Scale Image Recognition," Sep. 2014, [Online]. Available: http://arxiv.org/abs/1409.1556

[21] C. Shorten and T. M. Khoshgoftaar, "A survey on Image Data Augmentation for Deep Learning," *J Big Data*, vol. 6, no. 1, Dec. 2019, doi: 10.1186/s40537-019-0197-0.

[22] E. K. Reddy, "Application of Convolutional Neural Network in the Segmentation and Classification of High-Resolution Remote Sensing Images," 2022.

[23] S. Yang, W. Xiao, M. Zhang, S. Guo, J. Zhao, and F. Shen, "Image Data Augmentation for Deep Learning: A Survey," Apr. 2022, [Online]. Available: http://arxiv.org/abs/2204.08610

[24] L. Perez and J. Wang, "The Effectiveness of Data Augmentation in Image Classification using Deep Learning," Dec. 2017, [Online]. Available: http://arxiv.org/abs/1712.04621

[25] C. Shorten and T. M. Khoshgoftaar, "A survey on Image Data Augmentation for Deep Learning," *J Big Data*, vol. 6, no. 1, Dec. 2019, doi: 10.1186/s40537-019-0197-0.

[26] S. Simon, N. Kolyada, C. Akiki, M. Potthast, B. Stein, and N. Siegmund, "Exploring Hyperparameter Usage and Tuning in Machine Learning Research." [Online]. Available: https://zenodo.org/record/7745740