CycleGAN-based Data Augmentation for Enhanced Radar-based Tree Defect Detection

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Ground penetrating radar has become a prominent tool for non-destructive health assessment of trees. Particularly, it has been used for imaging the tree roots to distinguish the healthy and rotten roots and the interiors of the tree trunks to detect structural defects (e.g., cavity and decay). Recently, a stand-off radar has been proposed to rapidly detect tree defects inside tree trunks (J. Qian, Y. H. Lee, K. Cheng, Q. Dai, M. L. M. Yusof, D. Lee, and A. C. Yucel, "Deep Learning-Augmented Stand-off Radar Scheme for Rapidly Detecting Tree Defects," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 62, Jun. 2024). This radar is operated on a straight slider for very rapid scanning and leverages novel deep learning techniques for real-time detection of the defects inside tree trunks, while achieving over 90% and 75% detection accuracy for tree trunk samples and living trees, respectively. However, the detection accuracy of such radar on living trees is limited due to the small size of the training dataset, since collecting radar measurements is time-consuming and labour-intensive. To this end, an effective data augmentation technique for generating a large dataset is needed, which will also be beneficial for large dataset generation for other AI-based radar detection and imaging technologies.

In this study, we propose a Cycle Generative Adversarial Network (CycleGAN)-based data augmentation method to generate realistic radar B-scans that closely resemble real measured B-scans. Particularly, the proposed CycleGAN transforms the synthetic B-scans, generated through simulations of tree trunks, into realistic measured B-scans. Unlike conventional GANs, which require paired data for training, CycleGAN leverages unpaired datasets and uses two generators to perform style transformation tasks. In addition, CycleGAN incorporates a cycle consistency term into the GAN's loss function to ensure that the generated images closely resemble their corresponding input images (J. Zhu, T. Park, P. Isola, and A. A. Efros, "Unpaired Image-to-image Translation using Cycle-consistent Adversarial Networks," *IEEE International Conference on Computer Vision (ICCV)*, pages 2242–2251, 2017). To accurately transform the synthetic B-scans to realistic B-scans for tree defect detection, our proposed CycleGAN incorporates (i) a texture loss term into the cycle loss function and (ii) a down-sampling process within the residual blocks of the generators. With these enhancements, the generated realistic B-scans demonstrate high consistency with real measured B-scans, achieving a structural similarity index of 0.79 and a mean square error of 0.01. These results validate the proposed scheme's ability to effectively expand training datasets and lay the groundwork for improving network performance in detecting tree defects.