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# Sentinel-2 Super-Resolution with Real-ESRGAN using Satellite and Aerial Image Pairs and Color Correction Techniques

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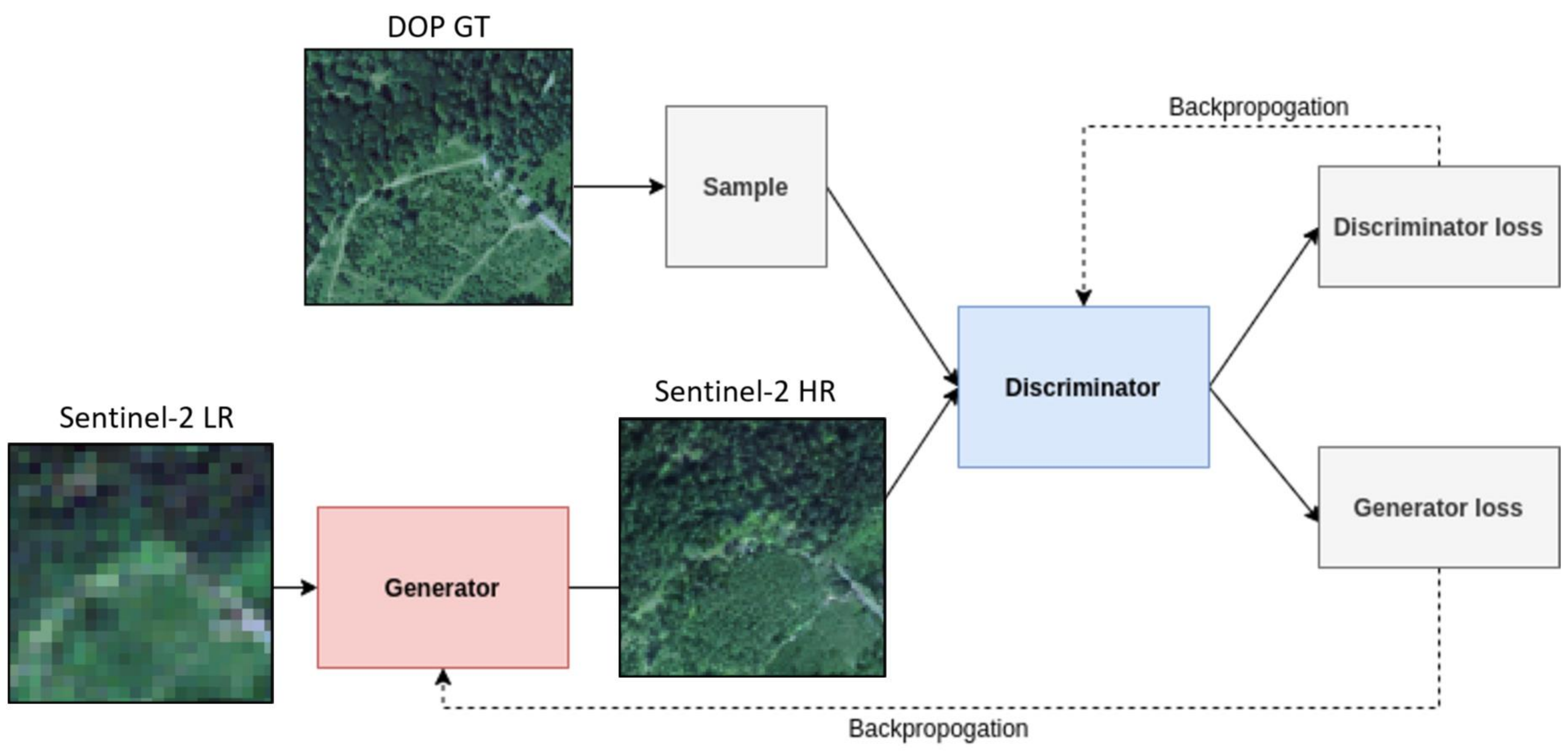
## Image Super-Resolution with Satellite and Aerial Image Pairs

Satellite datasets, like Copernicus Sentinel-2, are free and offer high temporal resolution, with every point on Earth imaged approximately every five days. However, their low spatial resolution of 10 meters per pixel in the visual range makes it difficult or even impossible to recognize a wide range of objects. Common methods to enhance spatial resolution in remote sensing include interpolation filters or pan-sharpening techniques when higher-resolution panchromatic images are available. These techniques are employed to address the limitation of low spatial resolution in remote sensing.

Additionally, modern super-resolution techniques based on artificial intelligence (1) have been developed to artificially enhance image resolution through machine learning.

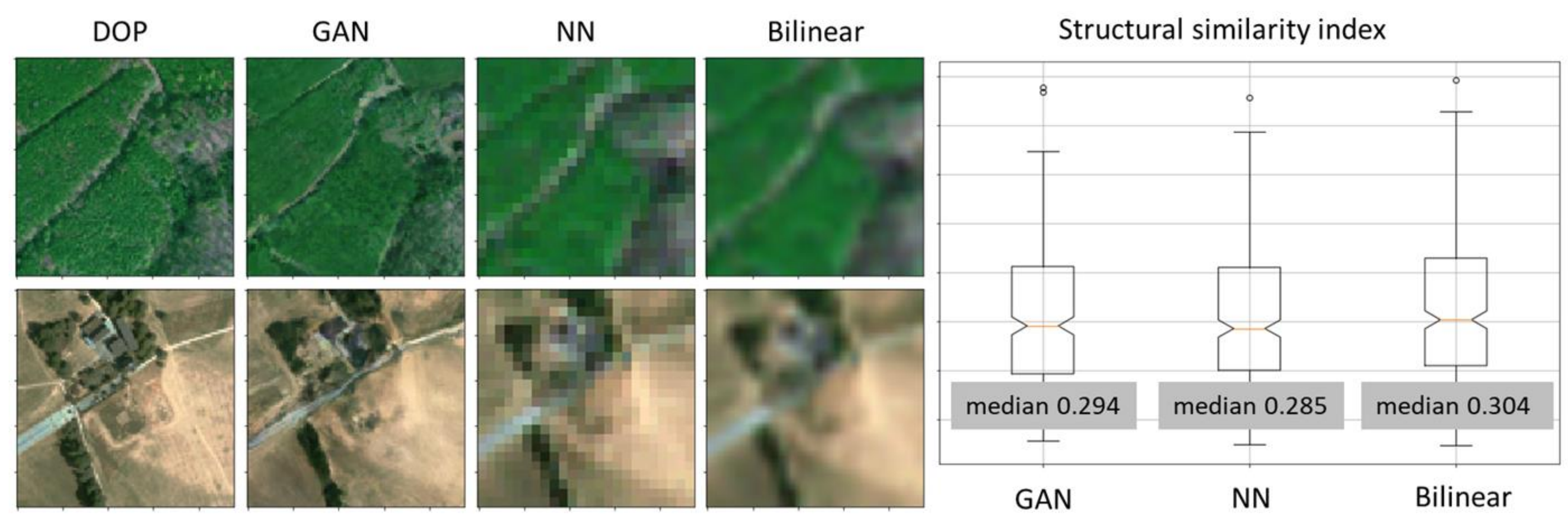



*Schematic representation of the Real-ESRGAN architecture with image pairs of digital orthophotos and Sentinel-2 data, image data: © European Union, contains Copernicus Sentinel-2 data [2024] and GeoBasis-DE/BKG [2024]*

Here, an Enhanced Super-Resolution Generative Adversarial Network, Real-ESRGAN (2), is chosen. By using purely synthetic training data, the Real-ESRGAN improves the original ESRGAN model (3) for practical recovery of low-resolution images with unknown and complex degradations. It seeks to address complex degradations that is encompassed in real-world degraded images. Complexity of the degradation is simulated using a multi-order degradation process which consists of running images through a multi degradation of process of blur, down-sampling, noise, JPEG compression, inclusion of ringing and overshoot artifacts. This approach has shown to produce superior visual performance compared to previous methods in various real-world datasets.

Additionally, combined fine-tuning is performed with image pairs of Sentinel-2 data (LR) and digital orthophotos as ground truth (GT) to produce a super-resolution Sentinel-2 output (HR) with a scale factor of 4 for the use case. For this purpose, a scene is selected from the LR images that were taken at the same time as GT if possible. To ensure consistency of Earth's surface within a selected image, a deviation of +- 6 days is selected as the maximum temporal difference. 10,000 image pairs are generated containing various landscape scenes. These image pairs are then used for the various training purposes. The SR images generated after the training has been completed are created without providing a GT image.

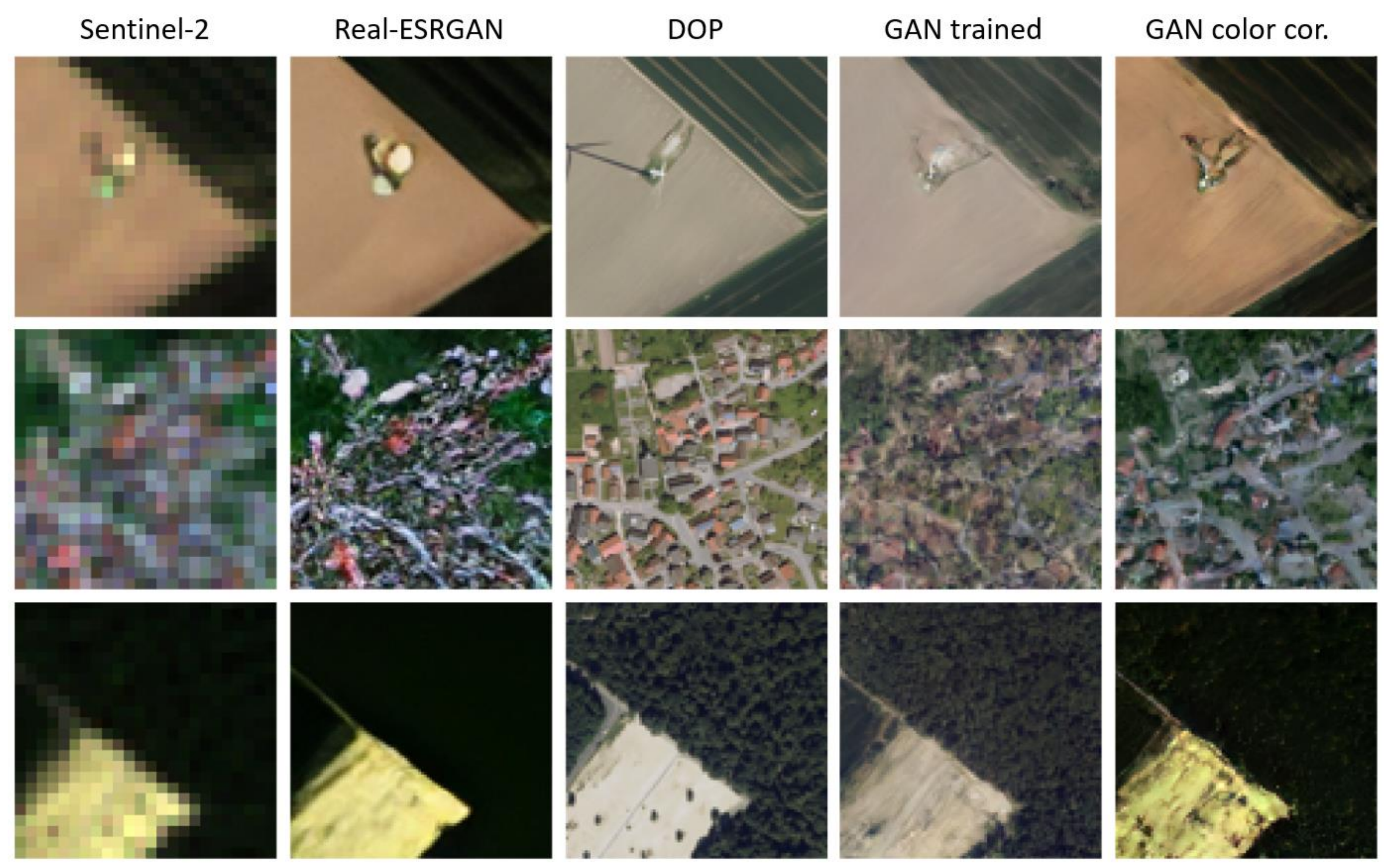
(1):Gupta, A., Mishra, R. & Zhang, Y. (2024). SenGLEAN: An End-to-End Deep Learning Approach for Super-Resolution of Sentinel-2 Multiresolution Multispectral Images. In IEEE Transactions on Geoscience and Remote Sensing, vol. 62 (pp. 1-19).
(2): Wang, X., Xie, L., Dong, C., & Shan, Y. (2021). Real-ESRGAN: Training real-world blind super-resolution with pure synthetic data. In Proceedings of the IEEE/CVF international conference on computer vision (pp. 1905-1914).
(3): Zhang, K., Liang, J., Van Gool, L., & Timofte, R. (2021). Designing a practical degradation model for deep blind image super-resolution. In Proceedings of the IEEE/CVF International Conference on Computer Vision (pp. 4791-4800).




*Although the optical interpretation shows a significantly better delineation for the GAN images, the image quality based on the SSIM is best for the bilinear interpolation Images: © European Union, contains Copernicus Sentinel-2 data [2024] and GeoBasis-DE/BKG [2024*

The generated images can then be evaluated based on various criteria. One useful metric is the similarity between images which can be determined by the structural similarity index (SSIM). SSIM is a measure of human-based perception comparison by considering luminance, contrast and structure between images. The subjective visual sighting certainly speaks in favor of the images generated by the finetuned Real-ESRGAN. In comparison to the bilinear or NN-interpolated images, the Real-ESRGAN generated images appear to have sharply defined contours of the individual structures and thereby making individual structures in the images more visible.

When manually comparing the LR and GT scenes, large discrepancies such as different color gradients and exposures become visible in the images due to the different sensors and lighting conditions. Therefore, a color balancing/correction strategy with cumulative distribution function of all 3 channels was performed. The subsequent fine-tuning shows clear differences to the previous run.




*Sentinel-2 data on the left, Super Resolution without finetuning beside it, in the middle the DOP as GT, to the right finetuning without adjusting the color values and on the far right the network with finetuning on the color correction. Image data: © European Union, contains Copernicus Sentinel-2 data [2024] and GeoBasis-DE/BKG [2024]*

## Conclusion

The application of Real-ESRGAN for super-resolution Sentinel-2 imagery in combination with digital orthophotos shows a significant improvement in image clarity and detail and enables better visualization in satellite data. The fine-tuning process, which includes color correction and the use of different landscape scenes, further improves the performance of the model and provides a robust solution for high-resolution remote sensing applications.

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