SUPER-RESOLUTION OF SATELLITE IMAGES USING GENERATIVE ADVERSARIAL NETWORKS FOR ENHANCED REMOTE SENSING APPLICATIONS

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Abstract

High-resolution satellite images are crucial for applications such as urban planning, agriculture monitoring, disaster management, and environmental studies. Due to sensor limitations and acquisition costs, low-resolution images often lack important spatial details. This paper presents a Generative Adversarial Network (GAN)-based super-resolution framework designed specifically for satellite imagery. The framework integrates a U-Net style generator with a PatchGAN discriminator and employs adversarial, perceptual, and pixel-wise loss functions. Experiments on Sentinel-2 and Landsat-8 datasets demonstrate significant improvements in Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) over conventional interpolation and deep learning-based methods. The proposed method effectively preserves texture and structural details, highlighting its potential for real-world remote sensing applications.

Keywords

GAN, Super-Resolution, Satellite Imagery, Remote Sensing, Deep Learning, U-Net Generator, PatchGAN, Discriminator, Perceptual Loss, Multispectral Imagery, PSNR, SSIM, High Frequency Details, Adversarial Training, Remote Sensing Applications, Image-to-Image Translation

Introduction

Satellite imagery is a cornerstone in geospatial analysis, enabling applications in urban development, agriculture, and disaster response. High-resolution (HR) images provide the fine-grained details necessary for accurate decision-making. However, limitations in satellite sensors and high acquisition costs often result in low-resolution (LR) images, which lack critical spatial information. Super-resolution (SR) techniques aim to reconstruct HR images from LR inputs. Traditional interpolation methods, such as bicubic and nearest neighbor, produce blurred or oversmoothed results. Deep learning-based SR methods, particularly Generative Adversarial Networks (GANs), have demonstrated superior performance in restoring textures and realistic details. This research proposes an original GAN-based framework tailored to satellite image super-resolution.
The key contributions include:

- Designing a U-Net based generator and PatchGAN discriminator for satellite imagery.
- Integrating adversarial, perceptual, and pixel-wise loss functions to ensure both realistic textures and structural fidelity.
- Extensive evaluation on Sentinel-2 and Landsat-8 datasets, demonstrating quantitative and qualitative superiority over baseline methods.

Problem Statement

Low-resolution satellite images often lack critical spatial and textural details due to sensor and cost limitations, making them insufficient for accurate analysis in remote sensing applications. Existing methods fail to effectively reconstruct high-frequency details while maintaining structural consistency. Therefore, there is a need for an efficient super-resolution approach that can enhance satellite imagery quality by generating high-resolution outputs from low-resolution inputs with improved realism and accuracy.

Literature Review

Super-resolution (SR) techniques have evolved significantly over time. Traditional methods such as nearest neighbor and bicubic interpolation are simple but often produce blurred images and fail to recover fine details.

Deep learning-based approaches, particularly Convolutional Neural Networks (CNNs), have improved reconstruction quality by learning complex mappings between low-resolution and high-resolution images. However, these methods may still lack perceptual sharpness.

Generative Adversarial Networks (GANs), such as SRGAN and ESRGAN, have further enhanced super-resolution by generating realistic textures and high-frequency details through adversarial training.

In the context of satellite imagery, super-resolution remains challenging due to variations in terrain, atmospheric conditions, and multispectral data complexity. These challenges highlight the need for more robust and specialized SR frameworks.

Methodology

The proposed super-resolution framework is based on a Generative Adversarial Network (GAN) architecture designed to enhance low-resolution satellite images.

- Low-resolution satellite images are taken as input from Sentinel-2 and Landsat-8 datasets.
- Images are preprocessed using normalization and data augmentation techniques.
- A U-Net based generator converts low-resolution images into high-resolution outputs.
- A PatchGAN discriminator evaluates the realism of generated images.
- Generated images are compared with ground truth high-resolution images.
- A combination of adversarial, perceptual, and L1 loss functions is used.
- The model is trained iteratively by updating generator and discriminator weights.
- The final output is an enhanced high-resolution satellite image with improved details.

Dataset and Preprocessing

Datasets: Sentinel-2 and Landsat-8. Preprocessing includes generating LR-HR pairs and data augmentation (rotation, flipping, brightness adjustment).

Result and Discussion

The proposed GAN-based super-resolution model is evaluated using PSNR and SSIM metrics. The results demonstrate significant improvement over traditional interpolation and existing deep learning methods, producing sharper images with better structural similarity.

The model effectively restores high-frequency details while preserving overall image structure, leading to enhanced visual quality. However, training instability may occur in complex regions such as cloudy areas. Additionally, the approach is computationally intensive, though it remains feasible with modern GPU resources.

Future Work

Future work includes hybrid GAN + Transformer architectures, lightweight models, multi spectral and hyperspectral image super-resolution, and domain adaptation techniques.

Conclusion

This paper presents a **GAN-based super-resolution framework** for satellite images, achieving superior PSNR and SSIM. It preserves textures and structural details, suitable for real-world applications.

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