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Multi-Constraint Generative Adversarial Network-Driven Optimization Method for Super-Resolution Reconstruction of Remote Sensing Images

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ABSTRACT: Remote sensing image super-resolution technology is pivotal for enhancing image quality in critical applications including environmental monitoring, urban planning, and disaster assessment. However, traditional methods exhibit deficiencies in detail recovery and noise suppression, particularly when processing complex landscapes (e.g., forests, farmlands), leading to artifacts and spectral distortions that limit practical utility. To address this, we propose an enhanced Super-Resolution Generative Adversarial Network (SRGAN) framework featuring three key innovations: (1) Replacement of L1/L2 loss with a robust Charbonnier loss to suppress noise while preserving edge details via adaptive gradient balancing; (2) A multi-loss joint optimization strategy dynamically weighting Charbonnier loss ($\beta = 0.5$), Visual Geometry Group (VGG) perceptual loss ($\alpha = 1$), and adversarial loss ($\gamma = 0.1$) to synergize pixel-level accuracy and perceptual quality; (3) A multi-scale residual network (MSRN) capturing cross-scale texture features (e.g., forest canopies, mountain contours). Validated on Sentinel-2 (10 m) and SPOT-6/7 (2.5 m) datasets covering 904 km² in Motuo County, Tibet, our method outperforms the SRGAN baseline (SR4RS) with Peak Signal-to-Noise Ratio (PSNR) gains of 0.29 dB and Structural Similarity Index (SSIM) improvements of 3.08% on forest imagery. Visual comparisons confirm enhanced texture continuity despite marginal Learned Perceptual Image Patch Similarity (LPIPS) increases. The method significantly improves noise robustness and edge retention in complex geomorphology, demonstrating 18% faster response in forest fire early warning and providing high-resolution support for agricultural/urban monitoring. Future work will integrate spectral constraints and lightweight architectures.

KEYWORDS: Charbonnier loss function; deep learning; generative adversarial network; perceptual loss; remote sensing image super-resolution

1 Introduction

Remote sensing image super-resolution technology serves as a pivotal means to enhance spatial resolution for critical applications including environmental monitoring, disaster emergency response, and precision agriculture. In agricultural contexts, high-resolution imagery enables precise identification of crop species and pest distribution patterns [1]; urban planning applications rely on clear delineation of building footprints and transportation networks [2]; disaster assessment requires rapid acquisition of detailed damage extent information [3]. In addition, recent studies have leveraged GAN-based frameworks to significantly improve resolution and feature continuity in large-area environmental monitoring tasks [4]. However, fundamental constraints—stemming from sensor physical limitations, atmospheric interference, and transmission bandwidth—result in pervasive resolution deficiencies during image acquisition. While traditional interpolation techniques like bicubic interpolation [5] offer rapid upsampling, they fail to



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