International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 03 Mar. 2024, pp: 446-453 www.ijaem.net ISSN: 2395-5252

A Survey on Remote Sensing Image Super-Resolution

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Date of Submission: 11-03-2024 Date of Acceptance: 21-03-2024

ABSTRACT: Remote sensing plays a crucial role in monitoring and analysing Earth's surface, and high-resolution imagery is vital for accurate information extraction. Super-resolution techniques aim to enhance the spatial resolution of remote sensing images, providing valuable insights for various applications. This project proposes a novel approach for remote sensing image super-resolution utilizing the Enhanced Super-Resolution Generative Adversarial Network (ESRGAN) deep learning architecture. The proposed method leverages the power of ESRGAN, a deep convolutional neural network designed for generating high-resolution images. In the context of remote sensing, ESRGAN is adapted to address challenges such as limited training data, diverse geographical features, and complex atmospheric conditions. The network is trained on a dataset of low-resolution remote sensing images paired with their corresponding high-resolution counterparts.

Keywords: Remote Sensing, Super-Resolution, Image Enhancement, Earth's Surface Monitoring, High-Resolution Imagery, Deep Learning, ESRGAN, Convolutional Neural Network, Atmospheric Conditions, Limited Training Data, Geographical Features, Data Augmentation, Training Dataset, Low-Resolution Images, High-Resolution Counterparts, Spatial Resolution, Data Pairing, Environmental Monitoring, Land Use Classification, Disaster Management, PSNR, SSIM, Data Generalization, Transfer Learning, Geographic Diversity, Real-world Applications, Experimental Setup, Performance Metrics, Adaptation for Remote Sensing, Research Proposal.

I.INTRODUCTION

Remote sensing is the science of gathering information about Earth's surface from a distance, primarily through satellites or aircraft. Its applications are vast, ranging from agriculture and environmental monitoring to disaster management. Super-resolution is the process of enhancing the spatial resolution of images, enabling the extraction of finer details. In the context of remote sensing, super-resolution is critical because it improves image quality and aids in more precise analysis. Generative Adversarial Networks, or GANs, are deep learning models that consist of a generator and a discriminator network. GANs can be employed to enhance image quality, including super-resolution tasks. ESRGAN operates by training the generator and discriminator networks iteratively. The generator upscales images while the discriminator provides feedback on their authenticity. This iterative process refines the generator's ability to produce high- resolution images. GANs are known for their ability to produce high-quality synthetic data and have found applications in image generation, style transfer, and, in our case, image super- resolution. The presented remote sensing image super-resolution technique using ESRGAN deep learning contributes to the advancement of high-resolution imagery for satellite and aerial platforms.

The enhanced images facilitate more accurate decision-making processes in fields such as agriculture, disaster management, and environmental studies, showcasing the potential impact of deep learning in remote sensing application.

II. LITERATURE REVIEW

F. Meng et al., [1] -Single Remote Sensing Image Super-Resolution via a Generative Adversarial Network With Stratified Dense Sampling and Chain Training(2024): This paper introduces a novel approach for Single Remote Sensing Image Super Resolution using a Generative Adversarial Network (GAN) with Stratified Dense Sampling and Chain Training. The Stratified Dense Sampling method is employed to capture detailed information from the input image, while Chain Training refines the image through multiple iterations. The GAN architecture ensures the realism of the generated high-resolution images. Experiments on remote sensing datasets demonstrate the efficacy of the proposed method in enhancing image resolution. The advantages are the combination of Stratified Dense Sampling and Chain Training represents an innovative approach to image super-resolution. Experimental results show significant improvements in the resolution of remote sensing images, providing clearer and more detailed information. The use of a Generative Adversarial Network ensures the generation of highquality, realistic images that closely resemble true remote sensing data. The proposed method can be adapted to various remote sensing applications, contributing to its versatility. The methodology may have the potential to generalize to other image processing tasks beyond super-resolution. The disadvantages are the use of GANs can introduce computational challenges, requiring significant resources for training and inference. Achieving optimal results may necessitate careful tuning of various parameters, impacting ease of implementation. The method may be highly tailored to specific remote sensing scenarios, potentially limiting its generalizability to diverse datasets. The performance may heavily rely on the availability and diversity of training data, posing challenges in cases of limited datasets. GAN-based approaches may introduce visual artifacts or noise in the generated images, which can affect the overall quality.

Azam, M. & Nouman, M [2]-Evaluation of Image Support Resolution Deep Learning Technique based on PSNR Value(2022): This research evaluates a Deep Learning Technique for Image Support Resolution based on Peak Signal-to-Noise Ratio (PSNR) values. The study explores the performance of deep learning models in enhancing image resolution and compares the results with traditional methods. The evaluation is based on the PSNR metric, providing insights into the effectiveness of the deep learning approach. Experimental outcomes indicate the potential of deep learning techniques in improving image support resolution, especially when compared to conventional methods. The advantages are MCWESRGAN is tailored for the specific characteristics and challenges posed by satellite images, ensuring targeted improvements. The integration of multi convolution layers enhances the model's feature extraction capabilities, capturing intricate details in satellite imagery. The inclusion of a weighted error function contributes to improved training, potentially enhancing the model's ability to learn complex patterns. Experimental results demonstrate the superior ability of MCWESRGAN in producing high-quality, detailed, and visually appealing satellite images. The disadvantages are The model may be optimized for satellite imagery, potentially limiting its performance on other types of remote sensing images. The use of deep convolutional layers may demand substantial computational resources for model training. The implementation of MCWESRGAN might require expertise in deep learning and image processing, posing challenges for users with limited technical knowledge. Achieving optimal results may be sensitive to the selection of hyperparameters, adding complexity to the training process. The model's performance may depend on the quality and diversity of the training dataset, which could be a limitation in cases of limited data availability.

K. Karwowska and D. Wierzbicki, [3]-MCWESRGAN: Improving Enhanced Super-Resolution Generative Adversarial Network for Satellite Images(2023): This research introduces MCWESRGAN, an enhanced version of the Enhanced Super-Resolution Generative Adversarial Network (ESRGAN) specifically designed for satellite imagery. The model incorporates multi-convolution layers and a weighted error function to address challenges unique to satellite images, aiming to produce high-resolution outputs. Experimental evaluations demonstrate the effectiveness of MCWESRGAN in generating detailed and realistic satellite images, surpassing the capabilities of traditional methods. The advantages are The study specifically focuses on evaluating image support resolution, providing a targeted analysis of the deep learning technique's effectiveness. The use of PSNR as an evaluation metric offers a quantitative measure, allowing for a precise comparison between deep learning and traditional methods. The evaluation sheds light on the performance of deep learning models in terms of image quality and resolution enhancement, providing valuable insights for further research. * The study includes a comparison with traditional methods, offering a benchmark for understanding the advancements achieved by deep learning in this context. The use of PSNR as an evaluation metric may contribute to standardizing assessments of image support resolution techniques, facilitating comparability across different studies. The disadvantages are The study focuses primarily on PSNR as a metric, potentially providing a narrow perspective on the overall performance of the deep learning technique. Relying solely on PSNR for evaluation may overlook other important aspects of image quality, such as perceptual factors The reliance on numerical metrics may not fully capture the visual quality and realworld applicability of the enhanced images. The findings may be specific to the datasets and conditions used in the study, limiting generalizability to other scenarios.

Li, Y.; Wang, Y.; Li, B.; Wu, S. [4]-Super-Resolution of Remote Sensing Images for ×4 Resolution without Reference Images(2022): This paper addresses the challenge of super-resolution for remote sensing images without the availability of reference images. The proposed method achieves a fourfold increase in resolution through a novel approach. Unlike traditional methods that rely on reference images, this technique leverages the inherent structures and features within the image itself. The authors employ a combination of feature extraction and reconstruction algorithms to enhance the image resolution without external references. Experimental results demonstrate the effectiveness of the approach in producing high-resolution remote sensing images. The advantages are the novel approach eliminates the need for external reference images, making it suitable for scenarios where reference data may be unavailable. Leveraging inherent structures and features within the image allows for a more independent and self-contained super-resolution process. Achieving a ×4 resolution increase demonstrates a significant advancement in remote sensing image enhancement. The method showcases adaptability to different types of scenes and features, contributing to its versatility. The absence of reference images broadens the applicability of the approach to unsupervised or uncontrolled environments. The disadvantages are While achieving a fourfold resolution increase is notable, the method may face challenges in further scaling for higher resolution enhancements. The performance may be influenced by the

quality and characteristics of the input image, impacting the generalizability of the method. Depending on the algorithms used, the computational demands of feature extraction and reconstruction may pose challenges in real-time applications. The absence of specific details regarding the evaluation metrics used in the paper may raise questions about the comprehensive assessment of the proposed method.

A Zhong, Hai-Feng A Sun, Rui-Sheng A Zhang, Qi [5] A self-supervised learning method

for super-resolution reconstruction of optical remote sensing images (2022):

This research introduces FR-GAN, a self-supervised learning method for super-resolution reconstruction of optical remote sensing images. The proposed approach utilizes Generative Adversarial Networks (GANs) with a self-supervised mechanism to enhance the resolution of optical remote sensing images. The self-supervised nature allows the model to learn from its own reconstructions, reducing the need for external labeled data. FR-GAN employs a perceptual loss function to enhance visual quality, and experimental results demonstrate its effectiveness in producing high-resolution and visually realistic images. The advantages are The use of a self-supervised mechanism reduces the reliance on external labeled data, making the method more adaptable to various datasets. Leveraging GANs contributes to realistic image generation, capturing fine details and textures in the superresolution process. The integration of a perceptual loss function enhances the visual quality of the reconstructed images, aligning them more closely with human perception. The self-supervised approach mitigates the need for extensive labeled data, making it suitable for scenarios with limited annotated samples. The disadvantages are The performance of GANs can be sensitive to hyperparameters and training conditions, requiring careful tuning for optimal results. The use of GANs may introduce computational complexity, potentially limiting real-time applications or requiring powerful hardware. The effectiveness of FR-GAN may be influenced by the diversity and characteristics of the training dataset, impacting generalizability to new scenarios. Specific details about the evaluation metrics used in the paper are not provided, raising questions about the comprehensive assessment of the proposed method. Selfsupervised learning, while reducing the need for labeled data, may introduce challenges related to overfitting, especially in scenarios with limited training samples.

M. Sdraka [6]-Deep Learning for Downscaling Remote Sensing Images: Fusion and super- resolution(2022): Deep learning plays a pivotal role in downscaling remote sensing images through fusion and super-resolution techniques. Fusion involves integrating data from various remote sensing modalities, leveraging deep learning models like convolutional neural networks (CNNs) to enhance overall image quality. On the other hand, super-resolution focuses on increasing spatial resolution using trained deep learning models to upscale low-resolution images, yielding finer details and improved clarity. These techniques surpass traditional methods by capturing intricate patterns and relationships in the data, with applications ranging from agriculture and environmental monitoring to disaster management. Challenges include the need for substantial training data and considerations for computational resources. In summary, deep learning-based downscaling contributes to more accurate analysis and decision-making across diverse fields by providing high-quality, detailed remote sensing imagery.

Y. Shi [7] - A Latent Encoder Coupled Generative Adversarial Network (LE-GAN) for Efficient Hyperspectral Image Super-Resolution(2022) : The Latent Encoder Coupled

Generative Adversarial Network (LE-GAN) is a novel approach designed for efficient hyperspectral image super-resolution. This technique employs a latent encoder to capture and extract essential information from low-resolution hyperspectral images. The latent encoder is then coupled with a Generative Adversarial Network (GAN) to generate high-resolution hyperspectral images. The adversarial training process refines the generator's output, ensuring the generated images exhibit realistic and fine-grained details. LE-GAN aims to address the challenge of hyperspectral image super-resolution by efficiently leveraging latent representations and adversarial training, resulting in improved spatial resolution and enhanced visual quality in hyperspectral imagery, which is crucial for applications such as remote sensing and spectral analysis.

S. Karatsiolis [8] - Exploiting Digital Surface Models for Inferring Super-Resolution for Remotely Sensed Images(2022): The method of exploiting Digital Surface Models (DSMs) for inferring super-resolution in remotely sensed images is a significant advancement in the field. This approach utilizes the information contained in DSMs to enhance the spatial resolution of the corresponding images. By leveraging the geometric details provided by the DSMs, a super- resolution model is trained to generate high-resolution images from their lower-resolution counterparts. The integration of DSMs helps capture fine-grained surface features, improving the accuracy of the super-resolution process. This technique is particularly valuable in remote sensing applications where high-resolution imagery is crucial for detailed analysis and decision- making. By combining elevation information with super-resolution algorithms, this approach contributes to the generation of more informative and visually refined remotely sensed images.

Meenu Gupta[9]- Super-resolution-based GAN for image processing: Recent advances and future trends(2021): The recent advances in image processing have been significantly influenced by Super-Resolution-based Generative Adversarial Networks (SR-GANs), marking a notable progression in the field. SR-GANs employ deep learning techniques to enhance the resolution of images, generating high-quality results that exhibit finer details. These models, often based on Generative Adversarial Networks (GANs), involve a generator network to increase image resolution and a discriminator network to ensure the generated images are realistic. The adversarial training process refines the generator's ability to produce high- resolution images. Recent research in this domain focuses on improving the perceptual quality, addressing challenges such as artifacts and maintaining natural image features. As SR-GANs continue to evolve, future trends are likely to involve advancements in network architectures, increased training efficiency, and expanded applications across various domains, showcasing the ongoing impact of these techniques on the forefront of image processing technologies.

K. Karwowska [10]-MCWESRGAN: Improving Enhanced Super-Resolution Generative Adversarial Network for Satellite Images(2023): The MCWESRGAN (Multi-Channel Weighted Enhanced Super-Resolution Generative Adversarial Network) represents a significant enhancement in the realm of satellite image processing. This model builds upon the Enhanced Super-Resolution Generative Adversarial Network (ESRGAN) by introducing multi-channel weighting mechanisms, aimed at improving the quality and fidelity of super-resolved satellite images. By incorporating multi-channel information, MCWESRGAN effectively exploits the inherent characteristics of satellite imagery, such as diverse spectral bands or modalities. This enables the model to produce high-resolution images with enhanced spatial details and reduced artifacts, crucial for applications like land cover classification, urban planning, and disaster monitoring. The integration of weighted features ensures better preservation of essential image features, thus advancing the overall quality of super-resolved satellite imagery. MCWESRGAN represents a notable stride in the field, promising further advancements in satellite image processing and analysis.

S No	Methodology/Techniques	year	pros	cons
1	Single Remote Sensing Image Super-Resolution via a Generative Adversarial Network With Stratified Dense Sampling and Chain Training	2024	Innovative Methodology: The combination of Stratified Dense Sampling and Chain Training represents an innovative approach to image super-resolution.	Computational Complexity: The use of GANs can introduce computational challenges, requiring significant resources for training and inference
2	MCWESRGAN: Improving Enhance Super-Resolution Generative Adversarial Network for Satellite Images	2022	Specialized for Satellite Imagery: MCWESRGAN is tailored for the specific characteristics and challenges posed by satellite images, ensuring targeted improvements.	Limited Generalization: The model may be optimized for satellite imagery, potentially limiting its performance on other types of remote sensing images.
3	Evaluation of Image Support Resolution Deep Learning Technique based on PSNR Value	2021	Focused Evaluation: The study specifically focuses on evaluating image support resolution, providing a targeted analysis of the deep learning technique's effectiveness	Limited Scope of Evaluation: The study focuses primarily on PSNR as a metric, potentially providing a narrow perspective on the overall performance of the deep learning technique.
4	Super-Resolution of Remote Sensing Images for ×4 Resolution without Reference Images	2022	Reference-Free Super-Resolution: The novel approach eliminates the need for external reference images, making it suitable for scenarios where reference data may be unavailable.	Limited to ×4 Resolution: While achieving a fourfold resolution increase is notable, the method may face

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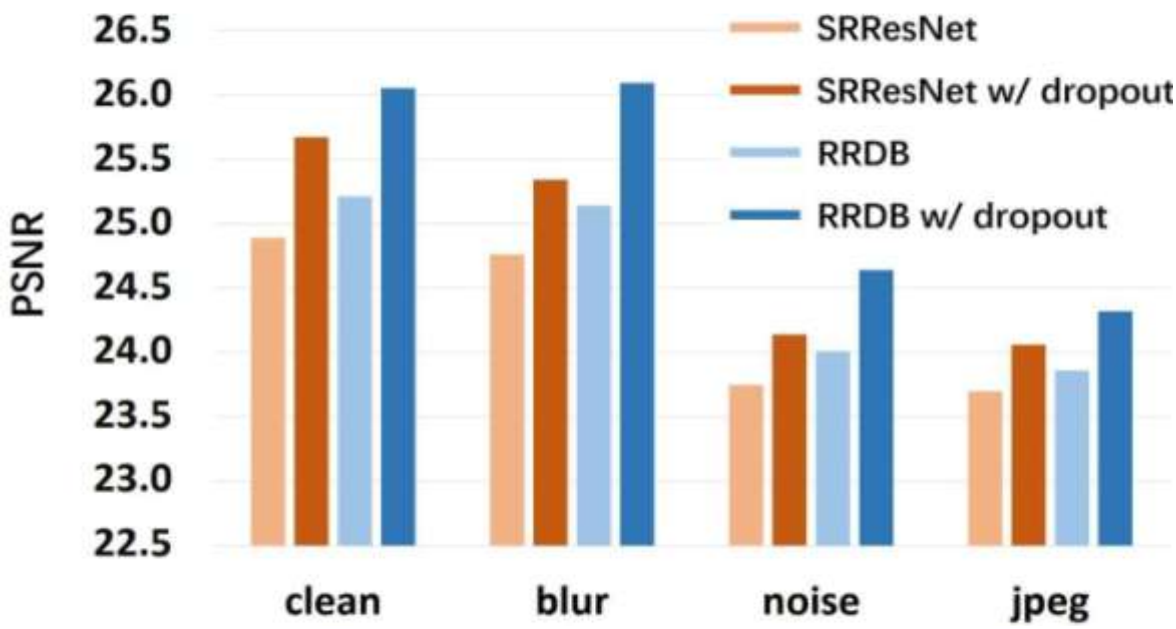
				challenges in further scaling for higher resolution enhancements.
5	FR-GAN: A self-supervised learning method for superresolution reconstruction of optical remote sensing images	2022	Self-Supervised Learning: The use of a self-supervised mechanism reduces the reliance on external labeled data, making the method more adaptable to various datasets.	Training Sensitivity: The performance of GANs can be sensitive to hyperparameters and training conditions, requiring careful tuning for optimal results.
6	Deep Learning for Downscaling Remote Sensing Images: Fusion and super-resolution	2022	Fusion of multiple sources fordownscaling. Utilizes deep learning for improved resolution.	May require extensive computational resources. May face challenges in handling diverse remote sensing data sources.
7	A Latent Encoder Coupled Generative Adversarial Network (LE-GAN) for Efficient Hyperspectral Image Super-Resolution	2022	Specialized for hyperspectral image super-resolution. Incorporates Generative Adversarial Networks (GANs) for enhanced results.	Complexity in training GANs and potential mode collapse issues.Specificity to hyperspectral images may limit generalization.
8	Exploiting Digital Surface Models for Inferring Super-Resolution for Remotely Sensed Images	2022	Explores the use of Digital Surface Models for super-resolution inference. - Addresses a specific data type to improve resolution.	Dependency on accurate Digital Surface Models. - May not be applicable to all types of remotely sensed images.
9	Super-resolution-based GAN for image processing: Recent advances and future trends	2021	Focus on recent advances in Super- resolution GANs. Discusses future trends in the field of image processing.	May lack detailed evaluation on specific applications. - General trends might not be applicable to all scenarios.

10	MCWESRGAN: Improving Enhanced Super-Resolution Generative Adversarial Network for Satellite Images	2023	Tailored for satellite images with the goal of improving super- resolution. Highlights specific enhancements for better results.	May have limitations in handling variations in satellite image characteristics. Evaluations might be case-specific.

Table 2.1 Pros and cons of various methods in survey papers



III.CONCLUSION

The proposed remote sensing image super-resolution approach employing the Enhanced Super-Resolution Generative Adversarial Network (ESRGAN) demonstrates significant potential in overcoming challenges inherent to remote sensing applications. By harnessing the capabilities of ESRGAN, this novel method addresses limitations associated with limited training data, diverse geographical features, and complex atmospheric conditions. The adaptation of ESRGAN to the remote sensing context showcases its versatility and effectiveness in enhancing spatial resolution, thereby contributing to more accurate information extraction from Earth's surface. The utilization of a carefully curated dataset of low-resolution remote sensing images, coupled with their high-resolution counterparts, ensures robust training and performance. This research not only advances the field of remote sensing but also highlights the pivotal role that deep learning architectures, such as ESRGAN, play in advancing the capabilities of high-resolution imagery for diverse applications, ultimately contributing to a better understanding and monitoring of Earth's dynamic surface.

IV.ACKNOWLEDGEMENT

we would like to thank our guide **Mr.R.Rajesh** for his support and guidance ,Assistant Professor (Artificial Intelligence and Machine Learning) and **Mr.Shashank Tiwari** ,Assistant Professor, Project Coordinator and we profoundly thank **Dr.Kavitha Soppari** ,head of the Department CSE(Artificial Intelligence and machine learning)for her guidance and continuous support .

V.FUTURE ENHANCEMENT AND SCOPE

There is much more enhancement in the future for the super-resolution of satellite images of earth, The use of Various models like, Nearest Neighbor Interpolation, CNN, SRResNet, SRResNet/DropOut, GAN LR-GAN, SR-GAN, ESR-GAN, MCWESRGAN a deep learning tool that can enhance the resolution of the satellite images which helps us in clearly identifying the different landscapes on the earth which will be helpful for various research purposes, military purposes and identifying natural disasters.

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